User's Guide of SWAP version 2.0

Simulation of water flow, solute transport and plant growth in the Soil-Water-Atmosphere-Plant environment

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ABSTRACT

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This manual describes how the numerical model SWAP version 2.0 can be used to simulate vertical transport of weater, solutes and heat in variably saturated, cultivated soils. A brief theoretical description is followed by a technical description of model structure and general data flow. An extensive explanation is given of program inputs and outputs based on ASCII text files. The manual ends with examples using important features of the model.

Keywords: agrohydrology, drainage, evapotranspiration, irrigation, salinization, simulation model, SWAP, soil water, soil heat, soil heterogeneity, surface water management

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Summary

In an earlier report (Van Dam et al., 1997) the applied flow and transport concepts of SWAP and their background have been described. This report describes the structure of the model and how the model can be used. After the introduction, chapter 2 starts with a brief summary of the system modelled by SWAP and the flow and transport processes considered. Chapter 3 presents the model structure. SWAP includes 7 sub-models: Meteo, Crop (detailed general, detailed grass and simple), Soil, Irrigation and Timer. One simulation may consist of 70 sequential or parallel sub-runs. SWAP calculates first the potential crop growth for the entire sub-run period and next the actual crop growth in interaction with water flow, solute transport and heat flow. As the Soil sub-model forms the heart of SWAP, the order in which the boundary conditions and relevant processes are calculated in Soil, is shown in detail. The data flow to and from the sub-models is discussed. In order to adapt to a data base structure, the input of different kind of data (meteorology, crop, irrigation, soil, drainage, surface water) is divided over different input files. In chapter 4 all the input files are described. First an overview of required and optional input files is given, including their general format rules. Next the input files are discussed one by one, while of each file an example is shown. Chapter 5 explains the program execution and lists the output files that can be generated by the sub-models Crop, Soil and Irrigation. Chapter 6 describes an application and contains exercises to explain program use. The application refers to water and solute transport on a maize field in the Hupsel catchment. Exercises indicate the effect of different meteorological years, irrigation, different crops, soil texture, hysteresis of the retention function, scaling of the soil hydraulic functions, and different root density distributions. Also the effect of errors in soil profile description and of preferential flow on bromide leaching to surface water is shown. The final exercise applies to drainage design. In the annexes the SWAP subroutines and the main program variables are listed.

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1 Introduction

Knowledge of water flow and solute transport processes in the vadose zone is essential to derive proper management conditions for plant growth and environmental protection in agricultural and environmental systems. Numerical models are widely used as helpful tools to gain insight in the processes occurring in these complex systems and to analyse optional management scenarios.
One of these numerical models is SWAP (Soil-Water-Atmosphere-Plant), the successor of the agrohydrological model SWATR (Feddes et al., 1978) and some of its numerous derivatives. The experiences gained with the existing SWATR versions were combined into SWAP, which integrates water flow, solute transport and crop growth according to current modelling concepts and simulation techniques. Main improvements are accurate numerical solution of the Richards' flow equation and incorporation of solute transport, heat flow, soil heterogeneity, detailed crop growth, regional drainage at various levels and surface water management.
The model offers a wide range of possibilities to address both research and practical questions in the field of agriculture, water management and environmental protection.
DLO Winand Staring Centre and Wageningen Agricultural University have developed the computer model SWAP 2.0 in close co-operation.

2 Brief theoretical description

The theory of the processes simulated by SWAP 2.0 is extensively described by Van Dam et al. (1997). This chapter summarises the most important theoretical concepts, which should be known for proper use of the program.

2.1 System definition

SWAP is a computer model that simulates transport of water, solutes and heat in variably saturated top soils. The program is designed for integrated modelling of the Soil-Atmosphere-Plant System (figure 1). Transport processes at field scale level and during whole growing seasons are considered. System boundaries at the top are defined by the soil surface with or without a crop and the atmospheric conditions. The lateral boundary simulates the interaction with surface water systems. The bottom boundary is located in the unsaturated zone or in the upper part of the groundwater and describes the interaction with regional groundwater.

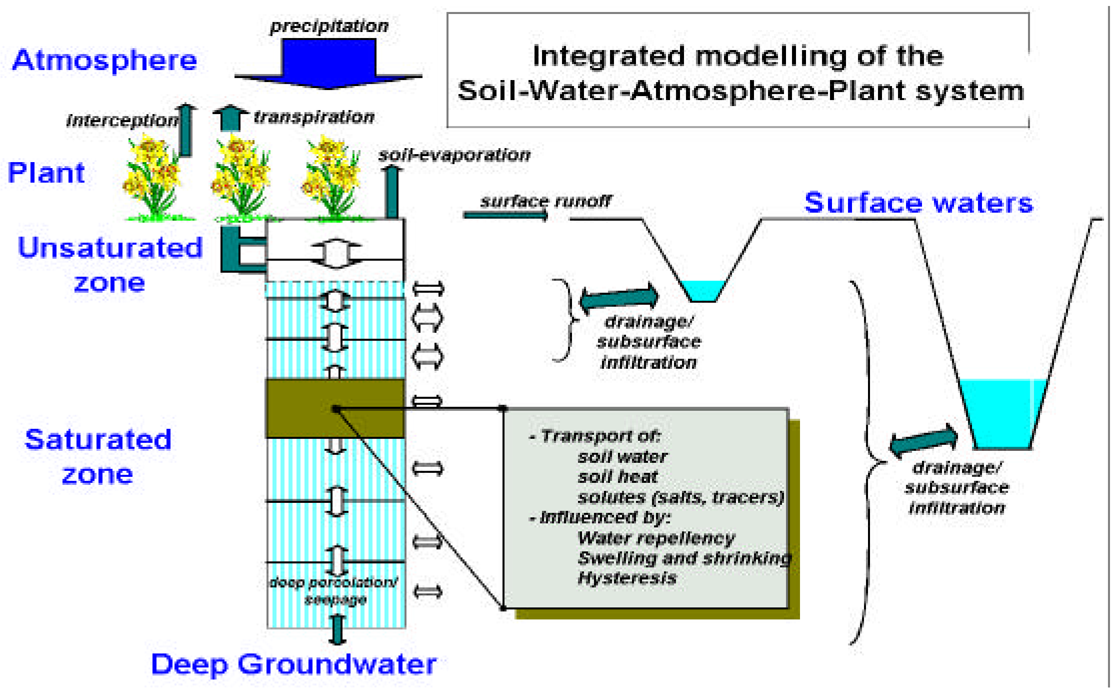


Fig 1. A schematised overview of the modelled system

2.2 Soil water flow

Spatial differences of the soil water potential cause flow of soil water. Darcy's equation is used to quantify these soil water fluxes. For one-dimensional vertical flow, Darcy's equation can be written as:

$$q = - K(h) \frac{\partial (h + z)}{\partial z} \quad (1)$$

where q is soil water flux density (positive upward) (cm d^{-1}), K is hydraulic conductivity (cm d^{-1}), h is soil water pressure head (cm) and z is the vertical co-ordinate (cm), taken positively upward.

Water balance considerations of an infinitely small soil volume result in the continuity equation for soil water:

$$\frac{\partial q}{\partial t} = - \frac{\partial q}{\partial z} - S(h) \quad (2)$$

where q is volumetric water content (cm^3 cm^{-3}), t is time (d) and S is soil water extraction rate by plant roots (cm^3 cm^{-3} d^{-1}).

Combination of Eq. 1 and 2 results in the well-known Richards' equation:

$$\frac{\partial}{\partial t} = C(h) \frac{\partial h}{\partial t} = \frac{\partial \left[K(h) \left(\frac{\partial h}{\partial z} + 1 \right) \right]}{\partial z} - S(h) \quad (3)$$

where C is the water capacity ($d\theta/dh$) (cm^{-1}).

Richards' equation has a clear physical basis at a scale where the soil can be considered as a continuum of soil, air and water. SWAP solves Eq. 3 numerically, subject to specified initial and boundary conditions and with known relations between q, h and K. These relationships, which are generally called the soil hydraulic functions, can be measured directly in the soil, or might be obtained from basic soil data. The Richards’ equation is solved using an implicit finite difference scheme as described by Belmans et al. (1983). This scheme has been adapted such that the solution applies both to the unsaturated and saturated zone, that water balance errors due to non-linearity of the differential water capacity are minimised and that calculated soil water fluxes at the soil surface are more accurate. Phreatic or perched groundwater levels are found at the transition from negative to positive soil water pressure heads.
Important features of the Richards’ equation are that it allows the use of soil hydraulic data bases and simulation of all kinds of management scenarios. The soil hydraulic functions are described by analytical expressions of Van Genuchten (1980) and Mualem (1976) or by tabular values. Hysteresis of the water retention function can be taken into account with the scaling model of Scott et al. (1983). Root water extraction at various depths in the root zone is calculated from potential transpiration, root length density and possible reductions due to wet, dry or saline conditions.

2.3 Soil heat flow

Soil temperature may affect the surface energy balance, soil hydraulic properties, decomposition rate of solutes and growth rate of roots. SWAP version 2.0 uses the soil temperatures only to adjust the solute decomposition rate. Combination of the general soil

heat flux equation and the equation for conservation of energy yields the differential equation for transient soil heat flow:

$$C_{heat} \frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\quad {}_{heat} \frac{\partial T}{\partial z} \right) \qquad (4)$$

where C_{heat} is the soil heat capacity (J cm^{-3} ^{o}C^{-1}) and T is the soil temperature (^{o}C).

This equation is solved either analytically or numerically. In the analytical solution a uniform thermal conductivity and soil heat capacity are assumed, and at the soil surface a sinusoidal temperature wave is adopted. In the numerical solution the thermal conductivity and the soil heat capacity are calculated from the soil composition and the volume fractions of water and air as described by De Vries (1975). At the soil surface the daily average temperature is used as boundary condition.

2.4 Solute transport

SWAP simulates convection, diffusion and dispersion, non-linear adsorption, first order decomposition and root uptake of solutes. This permits the simulation of ordinary pesticide and salt transport, including the effect of salinity on crop growth. In case of detailed pesticide or nutrient transport, daily water fluxes can be generated as input for other groundwater-quality models, such as PESTLA (Boesten and van der Linden, 1991; Berg and Boesten, 1998) and ANIMO (Groenendijk and Kroes, 1997; Kroes and Roelsma, 1998). The model SWAP simulates the residence time of solutes in the saturated zone analogous to mixed reservoirs. In this way solute transport from soil surface to surface water can be derived.

2.5 Crop growth

Crop growth can be simulated by the code WOFOST 6.0 (Hijmans et al., 1994). The cropping pattern may consist of maximal three crops per agricultural year.
WOFOST calculates the radiation energy absorbed by the canopy as function of incoming radiation and crop leaf area. Using the absorbed radiation and taking into account photosynthetic leaf characteristics, the potential gross photosynthesis is calculated. The latter is reduced due to water and/or salinity stress, as quantified by the relative transpiration, and yields the actual gross photosynthesis. Part of the carbohydrates (CH_2O) produced are used to provide energy for the maintenance of the existing live biomass (maintenance respiration). The remaining carbohydrates are converted into structural matter. In this conversion, some of the weight is lost as growth respiration. The dry matter produced is partitioned among roots, leaves, stems and storage organs, using partitioning factors that are a function of the crop phenological development stage. The fraction partitioned to the leaves, determines leaf area development and hence the dynamics of light interception. The dry weights of the plant organs are obtained by integrating their growth rates over time. During the development of the crop, part of living biomass dies due to senescence.
If simulation of crop growth is not needed, the user might just prescribe leaf area index, crop height, rooting depth, and root density distribution as a function of development stage.

2.6 Soil heterogeneity

Spatial variability of the soil hydraulic functions is described with the scaling concept of Miller and Miller (1956). The user may provide the reference curve and a number of scaling factors, and SWAP will generate for each scaling factor the soil hydraulic functions and the corresponding water and solute balance and relative crop yield.
In cracked clay soils the shrinkage characteristic is used to determine crack volume, area and depth. Water and solutes collected in the cracks will infiltrate at the crack bottom into the soil matrix or flow rapidly to the surface water. In the clay matrix, the Richard equation is applied for water flow and the convection-dispersion equation for solute transport.
Flow and transport in water-repellent soil is based on the concept of a mobile and an immobile soil volume. The actual mobile volume at a certain depth depends on the soil water pressure head. In the mobile volume the Richards' equation and the solute transport equation apply. In the immobile volume, the water flux is assumed to be zero. Solutes diffuse between mobile and immobile volume.

2.7 Irrigation and drainage

Irrigation may be prescribed at fixed times or scheduled according to a number of criteria. The scheduling option allows the evaluation of alternative application strategies. The timing criteria include allowable daily stress, allowable depletion of readily available water in the root zone, allowable depletion of totally available water in the root zone, and critical pressure head or water content at a certain depth.
Field drainage can be calculated with a linear flux-groundwater level relationship, with a tabular flux-groundwater relationship, or with drainage equations of Hooghoudt and Ernst. The use of drainage equations allows the design or evaluation of drainage systems.

2.8 Surface water system

At sub-regional level the interaction between soil water balance, crop growth and surface water management can be simulated. The surface water system can be partitioned in up to five channel orders, each defined by its bed level, bed width, side-slope and spacing. In each channel, except from the primary channel, the surface water has the same level, which is either input or calculated from the sub-region water balance. The water level of the primary channel is input. Drainage to each channel order is calculated with the corresponding drainage resistances. Also infiltration from the channels, using the corresponding infiltration resistances, is calculated when the surface water level is higher than the groundwater level. In case of surface water level as output, for each water management period, a fixed or automatic weir can be simulated. The user should provide a water management scheme that specifies the target level for surface water, the maximum mean groundwater level, the maximum soil water pressure head and the minimum air volume in the soil. SWAP will select the highest surface water level for which all criteria are met.

2.9 Sensitivity and limitations

To gain insight in the sensitivity of the results of the model SWAP to changes on some of its input parameters, a global sensitivity analysis was performed with this model by Wesseling and Kroes (1998). Generation of parameter values and the analysis were carried out with the statistical package Usage (Jansen and Withagen, 1997) for different

crop-soil combinations. The analysis was carried out with a range of meteorological years, which included average and extreme meteorological data. Input parameters were selected that are associated with a number of processes in the SWAP-model: soil physics, evapotranspiration, drainage, regional hydrology. For each input-parameter a distribution type, its average, variance, minimum and maximum value were selected using existing databases and expert-judgement. The analysis focussed on results as cumulative terms of the water balance and groundwater level. Some conclusions drawn from this analysis are:

- Boundary conditions (both upper and lower) are of crucial importance when applying the model SWAP;
- For all soil-crop combinations the soil and crop evaporation were strongly depending on the function describing the Leaf Area Index (LAI);
- Drainage, simulated as lateral discharge, is very sensitive to the surface water levels;
- High groundwater levels are strongly related to surface water levels; low groundwater levels depend on a combination of LAI, soil physical parameters and surface water levels; the average groundwater level is mainly determined by the level in the primary drainage system;
- At low values for the saturated hydraulic conductivity the model SWAP did not succeed in finishing the simulations within one hour cpu-time; this occurred for peat at values below 0.1 cm d^{-1}. and for clay at values below 0.06 cm d^{-1}. At these low values the Richards equation could not be solved within the specified cpu-time.

SWAP 2.0 is developed for calculations with daily meteorological input data. Exceptions are e.g. studies with surface water runoff, for which the user may provide actual, short time rainfall intensities. In general, model results should be analysed on a daily base. For many cases this will be sufficient; for analyses using more detailed and complete meteorological data other models such as SWAPS (Ashby et al., 1996) are recommended. Other limitations of this version of SWAP are:

- no simulation of regional groundwater hydrology;
- no interaction between crop growth and nutrient availability;
- no non-equilibrium sorption of pesticides and no simulation of metabolites

3 Technical model description

3.1 Model structure

A flow chart representing the main structure of the model Swap is given in figure 2. The structure of the program is such that one simulation run may consist of:

- A simulation period of 70 years (sequential sub-runs);
- Up to 70 scenarios of a growing period with a maximum length of one year (parallel sub-runs);
- Up to 70 sub-runs of a growing period with a maximum length of one year, with each sub-run its own soil hydraulic functions according to similar media scaling (parallel sub-runs).

Simulation and sub-run control parameters are initialised at the start of the simulation (figure 2, top left). The simulation starts for each sub-run with the potential crop production of the first day. Potential crop production is defined as the total dry matter production of a green crop surface that, during its entire growth period, is optimally supplied with water and nutrients, and grows without interference from weeds, pests and diseases. The production level is essentially determined by the prevailing weather conditions. To get an estimate of the potential production, the complete period of the sub-run is calculated (figure 2, block A). Once potential crop production is determined, the simulation of water-limited crop growth starts with an initialisation of sub-models for Timing and Soil. Optionally the Irrigation sub-model is initialised. Next the simulation starts the day at 00.00 hour with the intake of meteorological data after which the sub-model Soil solves the discretized equations for water flow, solute transport and heat flow (figure 2, block B). These calculations are performed with a reduced timestep, which will be decreased, maintained or increased according to numerical conditions for the solution of water flow and solute transport equations (see Van Dam et al., 1997, par. 2.4 and par. 3.3).
Within the sub-model Soil the top, lateral and bottom boundary conditions are determined first, after which the sink term of root water extraction is calculated. With boundary conditions and sink terms known, the Richards equation is solved, resulting in values for pressure heads and moisture contents for the next timestep. Soil temperatures are then determined by solving the heat flow equation. Parameters for hysteresis are updated and the daily water fluxes are integrated. If interaction with the surface water system is required (extended drainage), the various surface water flows are calculated. Also during each time step the solute transport equation is solved using the actual soil water fluxes. The sub-model Soil is called for each timestep until the end of the day.
Once the end of a day is reached and the calculations with the sub-model Soil are finished, the actual crop growth rates are determined and its corresponding state variables are integrated. After updates of some parameters the next day of simulations starts.
Once the last day of a simulation sub-run is reached the sub-model Soil is terminated and once the end of the last sub-run is reached the complete simulation ends.

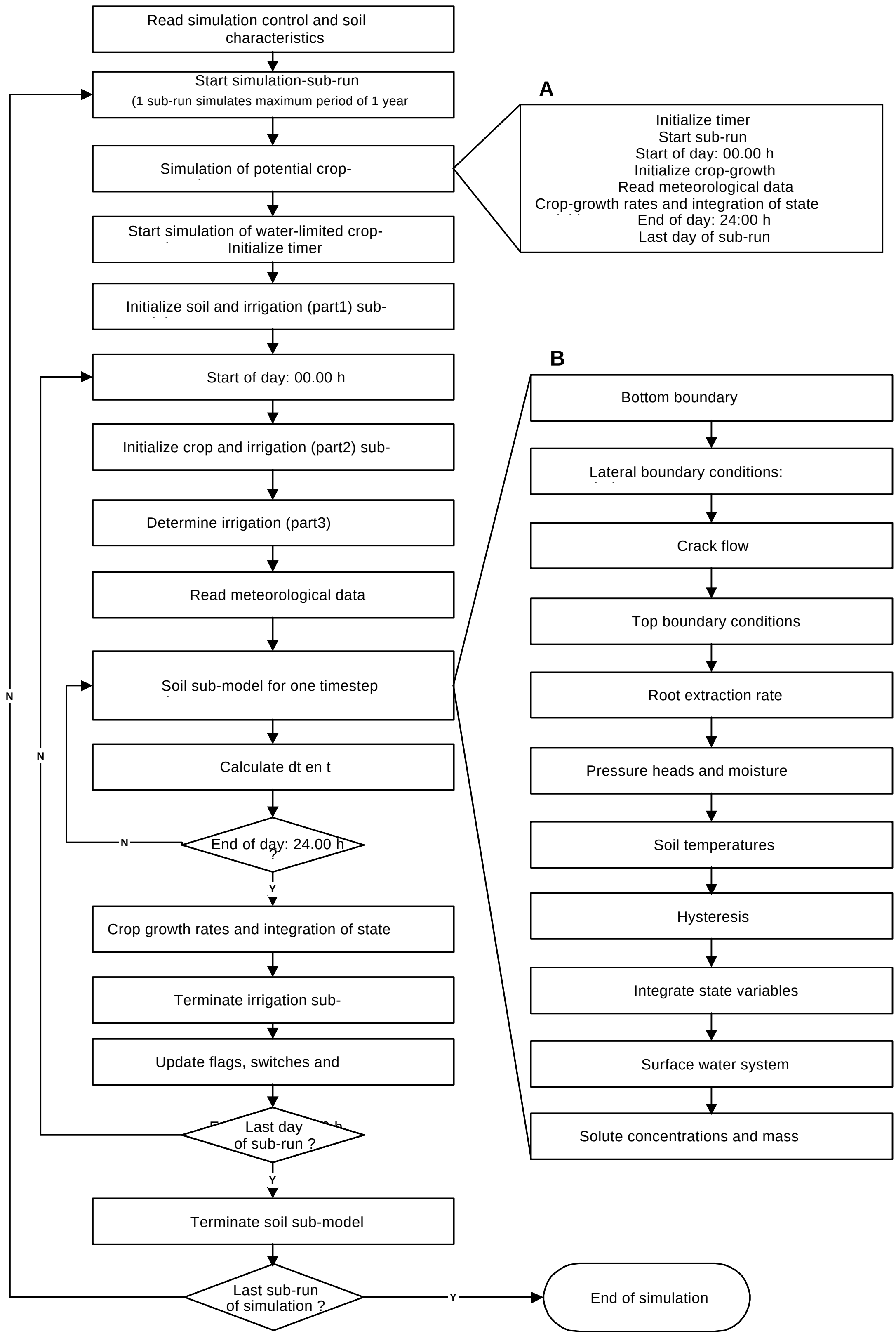


Fig 2. Main structure of Swap 2.0

3.2 General data flow

The main module of the model Swap consists of 7 submodels (figure 3): Meteo, Crop (detailed non-grass, detailed grass and simple), Soil, Irrigation and Timer. Sub-models are divided into parts for initialisation, rate calculation, integration and termination. The sub-models perform calls to subroutines, of which an overview is given in Annex B.
In order to facilitate tailored use of SWAP by researchers, Annex C contains the main variables of the program.
Each submodel requires specific input. In detail this will be explained in the next chapter. An overview of the general data flow is given in figure 3. A summary of required input and output data is given in respectively annex E and F.
Apart from one general input file, all files have variable file names and fixed file extensions. In figure 3 the file extensions are given between brackets.
The general input file (Swap.key) contains the switches that arrange the various simulation options.
Meteorological data can be supplied as daily data or, in a separate file, as short-term rainfall data to allow the calculation of surface runoff.
Values of crop parameters enter the corresponding sub-model for Crop growth, which can either be a detailed mechanistic model (Wofost) for annual crops or grassland, or a simple empirical crop model. Up to three crops per year are supported in any combination of the mechanistic and the empirical model. In case of grass production however, only one crop per year is allowed as the grassland is supposed to be permanent. The crop rotation scheme is given in a separate input-file.
The sub-model Soil reads spatial discretisation (geometry) and important soil characteristics. Separate input is given for soil physical data, bottom boundary conditions, surface water system, heat flow and solute transport.
The sub-model Irrigation reads from separate input-files: prescribed irrigation gifts or criteria to simulate irrigation gifts.
The sub-model Timer extracts information from the general input file Swap.key and the sub-model Soil.

3.3 Model extensions

For some applications the usual array lengths may be insufficient, or the user might wish to decrease some array lengths to use less memory. This is possible by changing parameter values that specify certain array lengths in the file PARAM.FI, and subsequent recompiling the program. The array lengths that might be changed are:

- maximum number of years in the simulation period, (standard 70)
- maximum number of compartments, (standard 40)
- maximum number of horizons, (standard 5)
- maximum number of applied irrigations, (standard 366)
- maximum number of open water levels (basic drainage) , (standard 366)
- maximum number of water levels primary system (ext. drainage) , (standard 366)
- maximum number of water levels secondary system (ext. drainage) , (standard 366)
- maximum oscillation of groundwater level (ext. drainage) , (standard 1000.0 cm)
- maximum number of management periods (ext. drainage) , (standard 52)

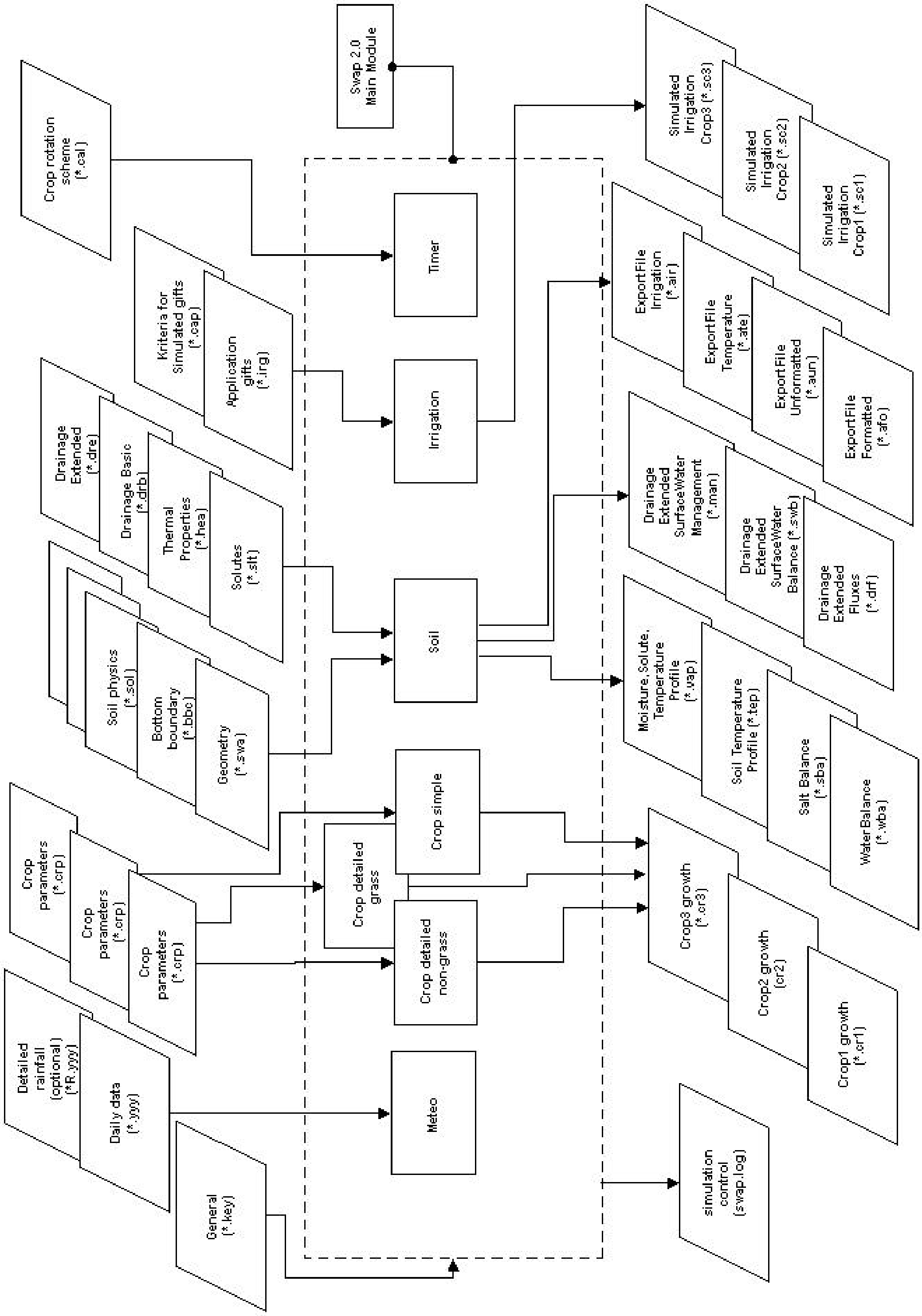


Fig 3 Main data flow of Swap 2.0

4 Program inputs

4.1 Introduction

A summary of all input files the model can handle is given in table 1. Some files are required, other files are optional. The general input file named Swap.key refers to the input files of the actual simulation. Apart from the name of the file Swap.key, all file names can be freely chosen. The file extensions are fixed however and indicated in bold in table 1. Other restrictions that apply to the file names are:

- The name of the meteo file with daily data consists of the name of the meteo station and an extension equal to last 3 digits of the year considered. The optional file with detailed rainfall has an equal name, with addition of an '**r**' before the extension (see table 1);
- A generic name is used for the input files *.swa (soil profile description), *.slt (solute transport data) and *.hea (heat flow data). In the example of table 1, the generic name is 'Hupsel'.

Table 1 Summary of input file requirements

Kind of data	Description of file-content (kind of parameters)	Filename	Required	Optional
General	Simulation and I/O-options	**Swap.key**	+	
Meteo	Daily data	Hupsel.**yyy**	+	
	Detailed rainfall	Hupsel**r.yyy**		+
Irrigation	Irrigation fixed	Hupsel.**irg**		+
	Irrigation calculated	Irrig.**cap**		+
Crop	Rotation	Year80.**cal**		+
	Detailed non-grass	Maize.**crp**		+
	Detailed grass	Grass.**crp**		+
	Simple crop model	MaizeS.**crp**		+
Soil related	Soil water	Hupsel.**swa**	+	
	Soil hydraulic functions	Sandt.**sol**	+	
	Drainage lateral: basic	Hupsel.**drb**		+
	Drainage extended: surface water	Hupsel.**dre**		+
	Bottom boundary conditions	Hupsel.**bbc**	+	
Heat	Heat flow	Hupsel.**hea**		+
Solute	Solute transport and transformation	Hupsel.**slt**		+

In the input files of each parameter the symbolic name, a description and an identification is given. The identification between square brackets uses the following convention:

1) range (recommended minimum and maximum)
2) unit
3) data type (I = Integer, R = Real*4, Ax = character string of x positions)

For example: [-5000 ..100 cm, R] means: value between –5000 and +100 with a unit in cm, given as a Real*4 data type (which means that a dot must be added).

Swap uses the units day for time, cm for length and mg for mass. Exceptions are the input of meteorological data (see par. 4.3), crop data (see par. 4.8 - 4.10), drain spacings and weir discharge coefficients in case of surface water management (see par. 4.14).

General rules for the formats of input files are:

- order of variables is fixed
- free format with structure 'VariableName' = 'value'
- comment in lines is allowed starting with '*' or '!'

- blank lines are allowed

In the following paragraphs each of the input files will be briefly discussed.

4.2 General information (Swap.key)

4.2.1 Section 1: Environment

The project name (maximum of 8 characters) will be used as a generic file name for several input files, notably the .SWA file (soil water flow data), the .SLT file (solute transport data) and the .HEA file (heat flow data).

The variable Path indicates the directory where the user wants to store the input and output files. An example is: 'c:\Swap\example\' or '..\example\'. If no characters (Path = '') are given then the program will assume that all input files are located at the current directory (the directory from which the model is executed). Output files will also be written to the directory specified with the variable Path.

```
**********************************************************************************
* Filename: SWAP.KEY
* Contents: SWAP 2.0 - General input data
**********************************************************************************
* Comment area:
*
*C Case: Water and solute transport in the Hupsel area,
*C       a catchment in the eastern part of the Netherlands
*C
*C Example of the User's Guide: reference situation
*C
*C A set of input data to explore SWAP
**********************************************************************************

**********************************************************************************
* Section 1: Environment
*
  Project = 'Hupsel'   ! Generic name for .SWA, .SLT and .HEA files, [A8]
  Path    = ''         ! Path to data directory, [A50]
  CType   = 1          ! Switch, computer type, [PC=1, VAX & Workstation =2]
  SWSCRE  = 1          ! Switch, display progression of simulation run, [Y=1, N=0]
**********************************************************************************

**********************************************************************************
* Section 2: Time variables
*
  SSRUN  = 01 01 1980 ! Start date of simulation run, give day month year, [3I]
  ESRUN  = 31 12 1980 ! End   date of simulation run, give day month year, [3I]
  FMAY   = 1          ! First month of the agricultural year, January = 1, [1..12, I]
  PERIOD = 0          ! Output interval, ignore = 0, [0..366, I]
  SWRES  = 1          ! Switch, reset output interval counter each year, [Y=1, N=0]
  SWODAT = 1          ! Switch, extra output dates are given in table, [Y=1, N=0]

* If SWODAT = 1, table with additional output dates
* Date records of type dd mm yyyy (max. 366), [1..31 1..12 1..3000, 3I]
  31 01 1980
  29 02 1980
  31 03 1980
  30 04 1980
  31 05 1980
  30 06 1980
  31 07 1980
  31 08 1980
  30 09 1980
  31 10 1980
  30 11 1980
  31 12 1980
* End of table
**********************************************************************************
```

File swap.key with general information: section 1 and 2

4.2.2 Section 2: Time variables

Start and end of the simulation period must be specified. The maximum length of the simulation period amounts 70 years. A year in SWAP does not necessarily start on January 1st, but rather on the first day of the month named `first month of the agricultural year'. Note that input files with time dependent data (except the meteo data files) relate to an agricultural year.

Swap output can be generated at regular intervals and additionally at irregular output dates, which must be specified explicitly. The day counter signalling the end of an output interval may be reset each sequential sub-run or just proceed.

4.2.3 Section 3: Meteorological data

The variable METFIL is the name of file with values of daily meteorological data and reference evapotranspiration data. The content of the file is discussed in paragraph 4.3. The name of the file should maximally be 7 characters long as it functions as the first part of the name of related meteo data files. The file extensions are derived from the three last digits of a year number. An example is: a file with the name 'Hupsel.998' contains meteo data from station Hupsel and year 1998. Note that internally SWAP calculates with actual year numbers (4 digits), so that no millennium problem will occur.

Latitude and altitude of the meteo station are used in the Penman Monteith equation. If reference evapotranspiration values are used instead of meteorological data (variable SWETR) then dummy values for latitude and altitude should be given.

The variable SWETR indicates whether SWAP should calculate potential evapotranspiration rates from daily meteorological data (using the Penman Monteith equation) or from daily reference evapotranspiration values.

In addition to daily rainfall data in the meteo files, detailed short timestep rainfall data may be specified in a separate data file. The variable SWRAI indicates if such a file will be used. A file with detailed rainfall related to the meteo data file given above should have the name 'HupselR.998'.

4.2.4 Section 4: In- and output files for the simulation runs

A simulation run may comprise a period of 70 years (sequential run). Alternatively, up to 70 simulations for the same year (or part of the year) with changing input conditions for this year can be carried out (parallel run). A sequential run for more than one year or a parallel run for more than one case contains a number of sub-runs. Each sub-run may have its own specific input data with respect to soil water boundary conditions and crop rotation scheme, whereas each crop (maximum = 3) in the scheme is related to a specific model type (detailed, detailed grass only or simple), cropping period and irrigation water application rules.

For each sub-run the next filenames (no extensions !) might be specified (optional can be skipped):

- IRGFIL - (optional) input file with fixed irrigation data (*.IRG). Fixed irrigations are an alternative to calculated irrigations and can be applied both within and outside a cropping period.
- CALFIL - (optional) input file with the crop rotation scheme (*.CAL). In case this file is not specified, bare soil is assumed throughout the simulation period.
- DRFIL - (optional) input file for the basic drainage routine (*.DRB) or the drainage routine extended to surface water (*.DRE). Which type to be specified (if any) is one of the run options in section 5.
- BBCFIL - input file with the bottom boundary condition (*.BBC).
- OUTFIL - generic name of output files for this year.

4.2.5 Section 5: Processes which should be considered

For the simulation of lateral drainage three options are available:

- no simulation of lateral drainage;
- simulation with the basic drainage routine (lateral drainage to maximally 5 drainage levels, no simulation of the surface water balance);
- simulation with the extended drainage routine (lateral drainage to maximally 5 drainage levels, taking into account simulation of the surface water balance).

The possibility to simulate solute and heat transport can be switched on or off.

4.2.6 Section 6: Optional output files

Under output options the user can specify whether additional output files of the extended drainage routine and the profile file (for each output day: vertical profiles of soil water content, solute concentration, soil temperature, soil water flux and solute flux) must be produced.

4.2.7 Section 7: Optional output files for water quality models

This section contains switches that arrange output to files which are commonly used by water quality models like PESTLA (Berg and Boesten, 1998) and ANIMO (Kroes and Roelsma, 1998). Options can be switched on and off and names for the related output files can be specified.

```
**********************************************************************************
* Section 3: Meteorological data
*
  METFIL = 'Wageni' ! File name without extension of meteorological data, [A7]
  LAT    =   52.0   ! Latitude of meteo station, [-60..60 degrees, R, North = +]
  ALT    =   10.0   ! Altitude of meteo station, [-400..3000 m, R]
  SWETR  =  0       ! Switch, use ETref values of meteo file [Y=1, N=0]
  SWRAI  =  0       ! Switch, use detailed rainfall data [Y=1, N=0]
**********************************************************************************


**********************************************************************************
* Section 4: In- and output files for the sub-runs
*
* Specify for each simulation sub-run (max. 70) the following 5 file names
* without extension (absence of file as '')  [A8]:
* 1 - the (optional) input file with fixed irrigation data [.IRG]
* 2 - the (optional) input file with the crop rotation scheme [.CAL]
* 3 - the (optional) input file for the basic drainage routine [.DRB]
*  or the (optional) input file for the extended drainage routine [.DRE]
* 4 - the input file with the bottom boundary condition [.BBC]
* 5 - generic name of output files
*
* IRGFIL    CALFIL    DRFIL     BBCFIL     OUTFIL
  'Hupsel'  'Year80'  'Hupsel'  'Hupsel'   'Result'
* End of table
**********************************************************************************


**********************************************************************************
* Section 5: Processes which should be considered

  SWDRA = 1  ! Switch, simulation of lateral drainage:
*              0 = No simulation of drainage
*              1 = Simulation with basic drainage routine
*              2 = Simulation with extended drainage routine

  SWSOLU = 1 ! Switch, simulation of solute transport [Y=1, N=0]
  SWHEA  = 1 ! Switch, simulation of heat transport [Y=1, N=0]
**********************************************************************************


**********************************************************************************
* Section 6: Optional output files, each run generates a separate file
*
  SWVAP = 1 ! Switch, output profiles of moisture, solute and temperature [Y=1, N=0]
  SWDRF = 0 ! Switch, output drainage fluxes, only for extended drainage [Y=1, N=0]
  SWSWB = 0 ! Switch, output surface water reservoir, only for ext. dr. [Y=1, N=0]
**********************************************************************************


**********************************************************************************
* Section 7: Optional output files for water quality models or specific use,
*            one file covers the total simulation period
*
  SWAFO  = 0       ! Switch, output file with formatted hydrological data, [Y=1, N=0]
  AFONAM = 'Result' ! File name without .AFO extension, [A8]

  SWAUN  = 0       ! Switch, output file with unformatted hydrological data, [Y=1, N=0]
  AUNNAM = 'Result' ! File name without .AUN extension, [A8]

  SWATE  = 0       ! Switch, output file with soil temperature profiles, [Y=1, N=0]
  ATENAM = 'Result' ! File name without .ATE extension, [A8]

  SWAIR  = 0       ! Switch, output file with irrigation data [Y=1, N=0]
  AIRNAM = 'Result' ! File name without .AIR extension, [A8]

* End of file ********************************************************************
```

File swap.key with general information: section 3, 4 , 5, 6 and 7

4.3 Daily meteo data (station.yyy)

SWAP uses daily evapotranspiration data. Also the rainfall data should be specified for each day, but in addition the actual rainfall intensities may be specified in the file stationnr.yyy.

The ranges, units and datatype of the meteo data are:

Day	[0..31 d, I]
Month	[1..12 m, I]
Year	[1..3000 y, I]
Daily global Radiation (RAD)	[0..5.E6 kJ/m2, R]
Minimum temperature (Tmin)	[-50..35 C, R]
Maximum temperature (Tmax)	[-30..60 C, R]
Average vapour pressure (HUM)	[0..10 kPa, R]
Average windspeed (WIND)	[0..50 m/sec, R]
Total rainfall (RAIN)	[0..1000 mm, R]
Reference evapotranspiration(ETref)	[0..100 mm,R]

Missing values in the input file should be indicated with -99.0 or lower. The following rules apply to missing meteo data:

- missing values of rainfall are never allowed;
- if potential evapotranspiration must be calculated, no missing values are allowed of the data RAD,Tmin, Tmax, HUM and WIND; potential evapotranspiration will be calculated in case ETref values are not used (specified in SWAP.KEY, section 3), or when ETref values are missing;
- no missing values for Tmin and Tmax are allowed if a crop is present or soil temperature must be simulated;
- no missing value for RAD is allowed in case the detailed crop model or the detailed grass model is active.

Violation of these rules cause program termination, after first writing the date and the cause of the fatal error to the log file.

4.4 Detailed rainfall (stationR.yyy)

Detailed rainfall data are necessary if runoff needs to be simulated accurately.

Each data record represents a reading from a raingauge, which is empty at 00.00 hours and will be emptied again at the end of the day (24.00 hours). This means that data entered should be cumulative over 24 hours.
Day, month, year, hour and minute should be entered as integers. Rain should be entered at least in tenth of a millimetre.
Note that in addition to the detailed rainfall, also the daily rainfall amounts should be specified in file station.yyy.

```
***********************************************************************
* Filename: Wageni.980
* Contents: SWAP 2.0 – Meteo data of Wageningen weather station
***********************************************************************
* Comment area:
*
*
**************************************************************************
*   Station   DD MM YYYY     RAD   Tmin   Tmax    HUM   WIND   RAIN   ETref
*             nr nr   nr   kJ/m2      C      C    kPa    m/s     mm      mm
**************************************************************************
 'Wageningen'  1  1 1980   2540.   -1.2    1.4    .62    3.5    6.2   -99.9
 'Wageningen'  2  1 1980   3520.   -6.5    1.4    .53    1.7     .0   -99.9
 'Wageningen'  3  1 1980   1510.   -8.2     .1    .49    2.2     .2   -99.9
 'Wageningen'  4  1 1980    740.    -.3    3.5    .66    4.5    7.0   -99.9
 'Wageningen'  5  1 1980    990.    2.8    5.1    .78    3.0    2.2   -99.9
 'Wageningen'  6  1 1980   1090.    3.8    6.0    .82    2.7    8.7   -99.9
…
…
 'Wageningen' 21 12 1980    650.     .1    4.0    .69    2.6    2.5   -99.9
 'Wageningen' 22 12 1980   1060.     .3    8.0    .80    2.9     .0   -99.9
 'Wageningen' 23 12 1980    480.    7.7   11.1   1.10    5.1    2.4   -99.9
 'Wageningen' 24 12 1980   1120.    8.4   12.0   1.02    5.1     .0   -99.9
 'Wageningen' 25 12 1980   1420.    2.8    9.8    .86    4.6    3.9   -99.9
 'Wageningen' 26 12 1980   2530.     .8    5.7    .64    3.8     .0   -99.9
 'Wageningen' 27 12 1980   3220.   -3.3    4.3    .60    1.1     .7   -99.9
 'Wageningen' 28 12 1980    870.   -2.7    3.4    .62    2.8     .0   -99.9
 'Wageningen' 29 12 1980    350.    3.3    7.2    .87    3.5     .0   -99.9
 'Wageningen' 30 12 1980    320.    6.4    8.2    .92    4.3     .0   -99.9
 'Wageningen' 31 12 1980    570.    5.7    8.6    .82    7.2    2.0   -99.9
```

File Wageni.980: daily meteorological data

```
********************************************************************************
* Filename: Wagenir.980
* Contents: SWAP 2.0 - detailed rainfall data of weather station
********************************************************************************
********************************************************************************
* Station    DD MM YYYY HR MN Rain
* Units:     nr nr   nr nr nr   mm
********************************************************************************
'Wageningen' 01 01 1980 14 00  3.0
'Wageningen' 01 01 1980 15 00  4.5
'Wageningen' 01 01 1980 17 00  6.2
'Wageningen' 01 01 1980 24 00  6.2
'Wageningen' 04 01 1980 06 00  1.5
'Wageningen' 04 01 1980 09 00  3.0
'Wageningen' 04 01 1980 10 00  6.9
'Wageningen' 04 01 1980 24 00  7.0
```

File wageniR.980: detailed rainfall data

4.5 Irrigation fixed (*.irg)

Two different types of irrigation can be specified in SWAP. The choice between the types depends on the economical and physical constraints of the irrigation area (see Van Dam et al, 1997, chapter 8). Either a fixed irrigation schedule can be specified, or irrigation application can be calculated according to a number of criteria. A combination of fixed and calculated irrigation is also possible. An example of this would be a pre-irrigation (flooding the field) before planting and later on irrigation based on crop development. Fixed irrigation can be specified the whole year round; irrigation scheduling can only be active during a cropping period. Both types of irrigation may overlap, but fixed irrigation has priority: if irrigation is prescribed on a certain day, no irrigation will be calculated for the same day.

This paragraph described the input data for a fixed irrigation schedule. These input must be specified in a file with extension *.IRG and must be given for each year with fixed irrigations, as indicated in SWAP.KEY, section 4.

The type of irrigation can be specified as being: a sprinkling (0) or a surface (1) irrigation. In case of sprinkling irrigation, interception will be calculated.

```
**********************************************************************************
* Filename: Hupsel.IRG
* Contents: SWAP 2.0 - Fixed irrigations
**********************************************************************************
* Comment area:
*
* Case: Water and solute transport in the Hupsel area,
*       a catchment in the eastern part of the Netherlands
*
* Example of the User's Guide: reference situation
*
* A set of input data to explore SWAP
**********************************************************************************


* List for each irrigation application (max 50 records):
* day month  depth     concentration    sprinkling (=0) or surface (= 1) application
*            mm        mg/cm3
  5   1      5.0       1000.0           1

* End of file ********************************************************************
```

File hupsel.irg: fixed irrigation

4.6 Irrigation calculated (*.cap)

In the previous paragraph (par. 4.5) a general description was given of the two options for irrigation.
This paragraph described the input data required for irrigation applications according to a number of criteria. Scheduling irrigation can be a more optimal strategy if certain objectives need to be reached in crop production, like economic returns or efficiency. In order for the irrigation scheduling to be active, the *.CAP file needs to be specified in the crop calendar file *.CAL.

4.6.1 Section 1: General

The water quality of the irrigation water and type of irrigation (sprinkling or surface) should be defined.

4.6.2 Section 2: Irrigation time criteria

Five different timing criteria can be chosen:

1) Allowable daily stress. This parameter determines the fraction [0..1, R] of the potential transpiration rate below which the actual transpiration rate should fall before initiating an irrigation.
2) Allowable depletion of readily available water. This parameter determines the depletable fraction [0..1, R] of the amount of water in the soil profile between h=-100 cm (field capacity) and the point at which water uptake is reduced (h_3, Fig 2.2 of Van Dam et al, 1997), before irrigation should be started. The point of reduced water uptake depends on the atmospheric demand. These parameters are crop specific and should be specified for each crop model in the crop file *.CRP. section Crop water use.
3) Allowable depletion of totally available water. This parameter determines the depletable fraction [0..1, R] of the amount of water in the soil profile between h=-100 cm (field capacity) and the wilting point (h_4, Fig 2.2 of Van Dam et al, 1997), before irrigation should be started. The wilting point is crop specific and should be specified for each crop model in the crop file *.CRP. section Crop water use.
4) Allowable depletion amount. This value determines a predetermined amount of water [0..500 mm, R] which can be extracted below h=-100 cm (field capacity), before irrigation should be started.
5) Critical pressure head or moisture content exceeded. In this case irrigation is initiated as soon as a hypothetical sensor in the soil indicates that the pressure head or moisture content drops below a specified value. This would be typical in many automated systems. The user should specify the depth of the sensor.

Each of the options gives the opportunity to define the timing criteria as function of crop development stages, giving the possibility of dynamic irrigation scheduling. It is conceivable that a crop can be allowed different levels of water and/or salinity stress depending on its development stage.

4.6.3 Section 3: Irrigation depth criteria

The back to field capacity option is useful in the case of sprinkler or micro irrigation. SWAP calculates the amount of irrigation water needed to bring the pressure heads in the root zone until h = -100 cm.
An over (positive) or under (negative) irrigation amount [0..100 mm, R] can be specified depending on the development stage of the crop. This can be useful if salts need to be leached or regular rainfall is expected.

The fixed depth irrigation [0..200 mm, R] is generally used when gravity irrigation systems are simulated, which generally allow little variation in application depth. Again it is possible to specify the irrigation amount depending on the crop development stage.

```
**********************************************************************************
* Filename: IRRIG.CAP
* Contents: SWAP 2.0 - Irrigation scheduling criteria and parameters
**********************************************************************************
* Comment area:
*
*
**********************************************************************************

**********************************************************************************
* Section 1: General
*
  ISUAS = 1   ! Switch, type of irrigation method during scheduling phase:
*               0 = sprinkling irrigation
*               1 = surface irrigation

  CIRRS = 0.0 ! solute concentration of scheduled irrig. water, [0..100 mg/cm3, R]
**********************************************************************************
```

File Irrig.cap: simulated irrigation, section 1: general info

```
**********************************************************************************
* Section 2: Irrigation time criteria
*
* Choose one of the 5 options:

  TCS1 = 1     ! Switch, criterion Daily Stress, [Y=1, N=0]
*
* If TCS1 = 1, specify mimimum of ratio actual/potential transpiration [0..1, R],
* as function of development stage [0..2, R], maximum 7 records:
* DVS  Ta/Tp
  0.0  0.95
  2.0  0.95
* End of table

  TCS2 = 0     ! Switch, criterion Depletion of Readily Available Water, [Y=1, N=0]
*
* If TCS2 = 1, specify minimal fraction of readily available water [0..1, R],
* as function of development stage [0..2, R], maximum 7 records:
* DVS  RAW
  0.0  0.95
  2.0  0.95
* End of table

  TCS3 = 0     ! Switch, criterion Depletion of Totally Available Water, [Y=1, N=0]
*
* If TCS3 = 1, specify minimal fraction of totally available water [0..1, R],
* as function of development stage [0..2, R], maximum 7 records:
* DVS  TAW
  0.0  0.50
  2.0  0.50
* End of table

  TCS4 = 0     ! Switch, criterion Depletion Water Amount, [Y=1, N=0]
*
* If TCS4 = 1, specify maximum amount of water depleted below field cap. [0..500 mm, R],
* as function of development stage [0..2, R], maximum 7 records:
* DVS  DWA
  0.0  40.0
  2.0  40.0
* End of table

  TCS5 = 0     ! Switch, criterion pressure head or moisture content, [Y=1, N=0]
*
* If TCS5 = 1, specify:
*
  PHORMC = 0   ! Switch, use pressure head (PHORMC=0) or water content (PHORMC=1)
  DCRIT = -30.0 ! Depth of the sensor [-100..0 cm, R]

* Also specify critical pressure head [-1.0E6..-100.0 cm, R] or moisture
* content [0.0..1.0 cm3/cm3, R], as function of development stage DVS [0.0..2.0, R]:
* DVS  VALUE
  0.0  1000.0
  2.0  1000.0
* End of table
**********************************************************************************

**********************************************************************************
* Section 3: Irrigation depth criteria
*
* Choose one of the 2 options:

  DCS1 = 1     ! Switch, criterion Back to Field Capacity, [Y=1, N=0]
*
* If DCS1 = 1, specify amount of under (-) or over (+) irrigation [0..100 mm, R],
* as function of development stage [0..2, R], maximum 7 records:
* DVS  dI
  0.0  0.0
  2.0  0.0
* End of table

  DCS2 = 1     ! Switch, criterion Fixed Irrigation Depth, [Y=1, N=0]
*
* If DCS2 = 1, specify fixed irrigation depth [0..200 mm, R],
* as function of development stage [0..2, R], maximum 7 records:
* DVS  FID
  0.0  0.0
  2.0  0.0
* End of table

* End of file ********************************************************************
```

File Irrig.cap: simulated irrigation, sections 2 and 3: timing and depth of irrigation

4.7 Crop rotation (*.cal)

Up to three crops can be simulated in each agricultural year using SWAP. For each crop, in a separate record, crop type, parameters, emergence and harvest and irrigation scheduling should be specified. Only one crop can grow in the field at one time, so emergence and harvest dates should be sequentially and cannot overlap.

The file containing the crop parameters, without the extension *.CRP, needs to be indicated here. The type of crop model should be indicated. SWAP uses the crop model WOFOST 6.0 (see Chapter 7 of Van Dam et al, 1997), but the user can also choose to use a simple crop model, which does not calculate crop development, or can use WOFOST attuned to permanent grass. During an agricultural year combinations of these three crop model types can be used. The user's choice of detail in the crop model will depend on the user's interest in detailed output or the availability of input data. Note that radiation and temperature data are necessary if the user specifies any of the options that use WOFOST.

Indicate the month and day of crop emergence, this will be the day the model uses to start calculation of crop development stage and plant transpiration. The emergence date should not be prior to an earlier crop's harvest date.

Indicate the harvest date, which will also be the day yield will be calculated in the detailed crop model and transpiration calculation will be terminated. The harvest date should not be later than a following crop's emergence date.

Indicate the day the scheduled irrigation should start. In most cases this is the same as the date of crop emergence. However a different date can be indicated, according to the users preferences.

```
**********************************************************************************
* Filename: Year80.cal
* Contents: SWAP 2.0 - Crop calendar
**********************************************************************************
*c Comment area:
*c
*c Rotation scheme Hupsel 1980
**********************************************************************************


* Specify for each crop (maximum 3):

* CRPFIL    = Crop data input file without .CRP extension, [A8]
* Type      = Type of crop model: simple = 1, detailed = 2, grass = 3
* CAPFIL    = Irrigation calculation input file with without .CAP extension, [A8]
* EMERGENCE = Emergence date of the crop
* END_crop  = Forced end of crop growth
* START_sch = Start of irrigation scheduling period

* CRPFIL   Type   CAPFIL    EMERGENCE  END_crop    START_sch
*                           d1 m1      d2 m2       d3 m3
 'MaizeS'  1      ''        01 05      15 10       01 05
* End_of_table
```

File year80.cal: crop rotation scheme

4.8 Detailed crop growth (*.crp)

Depending on the availability of input date the user can choose between several crop models. If the user has chosen the detailed crop model option in the crop calendar *.CAL, then, for each crop chosen by the user, detailed crop growth data need to be specified for the WOFOST 6.0 model.

Note that although the user can choose to use ETRef, the user will need daily radiation and temperature data in order to use the detailed crop model.

4.8.1 Section 1: Crop factor or crop height

Crop height or crop factor may used to determine the potential crop evapotranspiration. If daily meteorological data are used as input (paragraph 4.3) then both options are possible. If reference evapotranspiration is used as input then only crop factors can be used.

```
**********************************************************************************************
* Filename: WwheatD.CRP
* Contents: SWAP 2.0 - Crop data of detailed crop model
**********************************************************************************************
*c Comment area:
*c
*c Winter wheat - Tritium aestivum L.
**********************************************************************************************

* Section 1: Crop factor or crop height
*
  SWCF = 1 ! choice between crop factor [=1] or crop height [=2]
*
* If SWCF = 1, list crop factor [0.5..1.5, R],   as function of dev. stage [0..2 -,R]:
* If SWCF = 2, list crop height [0..1000 cm, R], as function of dev. stage [0..2 -,R]:
*
*       DVS   CF or CH   (maximum 15 records)
  CFTB =
          1.00   1.00
          2.00   1.00
* End of Table
**********************************************************************************************
```

File wheatd.crop: detailed crop growth, section 1

4.8.2 Section 2: Crop development

Growth simulation is started at the emergence date, specified by the user in the crop calendar file. A crop passes through the successive phenological stages from 0 to 2, depending on the development rate. The development rate can depend either on temperature or daylength or both. In modern cultivars, the day length can generally be ignored if an appropriate temperature sum is chosen. For more information the user should check Van Dam et al (1997) par. 7.2.

If temperature is chosen, appropriate temperature sums should be defined, which will determine the development stage of the crop. If daylength is chosen, appropriate optimum and threshold daylengths should be defined to determine the reduction factor for the development rate of the crop. If the combination option is chosen, the user should specify

both the temperature and the daylength parameters. The daily increase in temperature sum does not need to be linear. It is conceivable that the increase is lower at higher average temperatures. The relationship can be defined in a maximum of 15 data pairs. Finally the development stage at harvest should be defined.

4.8.3 Section 3: Initial values

The initial growth parameters needed are the initial crop weight, the leaf area index and the maximum relative increase of LAI.

4.8.4 Section 4: Green surface area

In the second (assimilates limited) growth stage the maximum increase in leaf area index is determined by the specific leaf area. The specific leaf area of a crop can differ depending on the development stage. SWAP allows introduction of a curve describing the specific leaf area in up to 15 data points as a function of the development stage.

To calculate total assimilation it is necessary to know the green area of the stems and storage organs since these can absorb radiation.

Under optimal conditions (constant 35 °C) leaves have a certain life span. Lower temperatures limit the life span of the leaves. Next to the optimal temperature of 35 °C, a lower threshold temperature, which is crop specific, should be specified.

4.8.5 Section 5: Assimilation

This section contains the parameters needed to calculate the assimilation rate from the solar radiation data. Detailed information about the assimilation calculations can be found in par. 7.3 through 7.5 of Van Dam et al (1997). The extinction coefficients and light use efficiency are needed to calculate a potential gross assimilation for the crop. These determine how much radiation can be used for assimilation. The assimilation rate is than reduced by either the phenological stage of the crop, the average daytime temperature or a low minimum temperature at night, when the assimilates are transformed.

The maximum CO2 assimilation rate (AMAX) is a function of the crop development stage. The user can enter a specific relationship (up to 15 data pairs) to characterise this relationship.

The reduction factor (TMPF) based on average daily temperature accounts for sub-optimum temperatures. The input allows for a relationship defined by up to 15 data pairs

The influence of a low minimum night temperature on the reduction factor of AMAX also can be defined by a relationship of up to 15 data pairs.

4.8.6 Section 6: Conversion of assimilates into biomass

The assimilates are transformed into structural biomass after subtraction of respiration for maintenance. Depending on the product formed, the efficiency of the conversion of primary photosynthates to structural plant material varies. Efficiencies are crop specific and should be specified in this section

4.8.7 Section 7: Maintenance respiration

An increase in temperature causes an increase in maintenance respiration. Generally a 10 °C temperature increase causes maintenance respiration to increase by a factor 2.

Respiration is dependent on relative maintenance coefficients of the specific crop organs. These coefficients are proportional to the dry weights of the plant organs.

Senescence will decrease respiration. The reduction factor (RFSE) is crop specific and may depend on crop development stage. The user can enter up to 15 data pairs to define this relationship.

4.8.8 Section 8: Partitioning

The partitioning of the produced structural plant material to the different plant organs is defined by partitioning factors (FR, FL, FS, FO), which each depend on crop development stage. Note that the sum of the partitioning factors for leaves, stems and storage organs should equal 1.0 at any development stage (see Par. 7.8 of Van Dam et al,1997)!

4.8.9 Section 9: Death rates

The user needs to define the death rate due to water and/or salinity stress. The death rate of the storage organs is considered to be zero. The user can specify a death rate of the roots (RDRR) and stems (RDRS) as a function of crop development stage. The death rate of the leaves is somewhat more complicated (see Par. 7.9 of Van Dam et al,1997), and was already defined in section 4.

4.8.10 Section 10: Crop water use

Both the water and the salinity stress will limit the potential transpiration of the crop. SWAP assumes that the reduction factors due to water and salinity stress are multiplicative.

The user should enter the pressure heads defining the root water extraction function. The soil water potential stress relationship (as depicted in fig 2.2 of Van Dam et al,1997) is used to calculate the water stress of the crop. For this relationship the user should specify the upper and lower limits of the root water extraction function.

If the Penman-Monteith equation is used, the user needs to supply the minimum canopy resistance RSC.

Under high atmospheric demand transpiration might decrease earlier than under low atmospheric demand. SWAP assumes a linear relationship between the potential transpiration rate and the threshold pressure head HLIM3.

4.8.11 Section 11: Salt stress

Reduction of water uptake due to salt stress needs input of a maximum salt tolerance value (EC value below which no salt stress occurs) and the slope of the EC and root water uptake reduction curve (see Par. 2.3 of Van Dam et al, 1997).

4.8.12 Section 12: Interception

The precipitation interception coefficient is used to calculate the amount of interception with the Braden (1985) concept. At increasing precipitation amounts, the interception asymptotically reaches the value COFAB*LAI cm, where LAI is the leaf area index.

4.8.13 Section 13: Root density distribution and root growth

The user may enter up to 15 data pairs to define the relative root density distribution as a function of the relative rooting depth. Any unit for the root density can be used; SWAP will normalise the root density distribution.

Root growth is calculated rather straightforward. The user needs to define the initial rooting depth, the maximum daily increase and the maximum rooting depth. The daily increase is equal to the maximum daily increase unless too few assimilates are available or the maximum rooting depth is reached.

```
**********************************************************************************************
* Section 2 : Crop development
*
  IDSL   = 0      ! Switch:
*                   0 = Crop development before anthesis depends on temperature only
*                   1 = Crop development before anthesis depends on  daylength only
*                   2 = Crop development before anthesis depends on both

* If IDSL = 1 or 2, specify:
  DLO     = -     ! Optimum daylength for crop development, [0..24 h, R]
  DLC     = -     ! Minimum daylength, [0..24 h, R]

* If IDSL = 0 or 2, specify:
  TSUMEA = 1255.0 ! Temperature sum from emergence to anthesis, [0..10000 C, R]
  TSUMAM =  909.0 ! Temperature sum from  anthesis to maturity, [0..10000 C, R]

* List daily increase of temperature sum [C, R] as function of av. day temp. [0..100 C, R]
*            ADT  DTSM    (maximum 15 records)
  DTSMTB =  0.00   0.00
           30.00  30.00
           45.00  30.00
* End of table

  DVSEND =  2.00  ! development stage at harvest [0..3.0 -, R]
**********************************************************************************************

**********************************************************************************************
* Section 3: Initial values
*
  TDWI   =  210.0 ! Initial total crop dry weight, [0..10000 kg/ha, R]
  LAIEM  = 0.1370 ! Leaf area index at emergence, [0..10 m2/m2, R]
  RGRLAI = 0.0070 ! Maximum relative increase of LAI per day, [0..1 m2/m2/d, R]
**********************************************************************************************

**********************************************************************************************
* Section 4: Green surface area
*
* List specific leaf area [ha/kg, R] as function of development stage [0..2, R]:
*          DVS     SLA    (maximum 15 records)
  SLATB = 0.00  0.0020
          2.00  0.0020
* End of table

  SPA    =  0.0   ! Specific pod  area, [0..1 ha/kg, R]
  SSA    =  0.0   ! Specific stem area, [0..1 ha/kg, R]
  SPAN   = 35.0   ! Life span of leaves at optimum conditions, [0..366 d, R]
  TBASE  =  0.0   ! Lower threshold temperature for ageing of leaves, [-10..30 C, R]
**********************************************************************************************

**********************************************************************************************
* Section 5: Assimilation
*
  KDIF   =  0.60  ! Extinction coefficient for diffuse visible light, [0..2 -, R]
  KDIR   =  0.75  ! Extinction coefficient for direct visible light, [0..2 -, R]
  EFF    =  0.45  ! Light use efficiency of single leaf, [0..10 kg/ha/hr/(Jm2s), R]

* List max. CO2 assimilation rate [kg/ha/hr, R] as function of dev. stage [0..2 -, R]:
*           DVS    AMAX    (maximum 15 records)
  AMAXTB = 0.00   40.0
           1.00   40.0
           2.00   20.0
* End of table

* List reduction factor of AMAX [-, R] as function of average day temp. [-10..50 C, R]:
*           ADT   TMPF    (maximum 15 records)
  TMPFTB = 0.00   0.01
          10.00   0.60
          15.00   1.00
          25.00   1.00
          35.00   0.00
* End of table

* List reduction factor of AMAX [-, R] as function of minimum day temp. [-10..50 C, R]:
*           MDT   TMNF    (maximum 15 records)
  TMNFTB = 0.00   0.00
           3.00   1.00
* End of table
**********************************************************************************************

**********************************************************************************************
* Section 6: Conversion of assimilates into biomass
*
  CVL    = 0.685  ! Efficiency of conversion into leaves,          [0..1 kg/kg, R]
  CVO    = 0.709  ! Efficiency of conversion into storage organs,  [0..1 kg/kg, R]
  CVR    = 0.694  ! Efficiency of conversion into roots,           [0..1 kg/kg, R]
  CVS    = 0.662  ! Efficiency of conversion into stems,           [0..1 kg/kg, R]
**********************************************************************************************
```

File wheatd.crop: detailed crop growth, sections 2-6

```
**********************************************************************************************
* Section 7: Maintenance respiration
*
  Q10    =  2.0   ! Rel. increase of respiration rate with temperature, [0..5 /10 C, R]
  RML    =  0.030 ! Rel. maintenance respiration rate of  leaves, [0..1 kgCH2O/kg/d, R]
  RMO    =  0.010 ! Rel. maintenance respiration rate of st.org., [0..1 kgCH2O/kg/d, R]
  RMR    =  0.015 ! Rel. maintenance respiration rate of   roots, [0..1 kgCH2O/kg/d, R]
  RMS    =  0.015 ! Rel. maintenance respiration rate of   stems, [0..1 kgCH2O/kg/d, R]

* List reduction factor of senescence [-, R] as function of dev. stage [0..2 -, R]:
*            DVS  RFSE    (maximum 15 records)
  RFSETB =   0.0  1.00
             2.0  1.00
* End of table
**********************************************************************************************

**********************************************************************************************
* Section 8: Partitioning
*
* List fraction of total dry matter increase partitioned to the roots [kg/kg, R]
* as function of development stage [0..2 -, R]:
*         DVS     FR      (maximum 15 records)
  FRTB = 0.00   0.50
         0.10   0.50
         0.20   0.40
         0.35   0.22
         0.40   0.17
         0.50   0.13
         0.70   0.07
         0.90   0.03
         1.20   0.00
         2.00   0.00
* End of table

* List fraction of total above ground dry matter incr. part. to the leaves [kg/kg, R]
* as function of development stage [0..2 -, R]:
*         DVS     FL      (maximum 15 records)
  FLTB = 0.00   0.65
         0.10   0.65
         0.25   0.70
         0.50   0.50
         0.70   0.15
         0.95   0.00
         2.00   0.00
* End of table

* List fraction of total above ground dry matter incr. part. to the stems [kg/kg, R]
* as function of development stage [0..2 -, R]:
*         DVS     FS      (maximum 15 records)
  FSTB = 0.00   0.35
         0.10   0.35
         0.25   0.30
         0.50   0.50
         0.70   0.85
         0.95   1.00
         1.05   0.00
         2.00   0.00
* End of table

* List fraction of total above ground dry matter incr. part. to the st. organs [kg/kg, R]
* as function of development stage [0..2 -, R]:
*         DVS     FO      (maximum 15 records)
  FOTB = 0.00   0.00
         0.95   0.00
         1.05   1.00
         2.00   1.00
* End of table
**********************************************************************************************
```

File wheatd.crop: detailed crop growth, section 7 and 8

```
**********************************************************************************************
* Section 9: Death rates
*
  PERDL = 0.030 ! Maximum rel. death rate of leaves due to water stress, [0..3 /d, R]

* List relative death rates of roots [kg/kg/d] as function of dev. stage [0..2 -, R]:
*           DVS   RDRR      (maximum 15 records)
  RDRRTB = 0.00   0.00
           1.50   0.00
           1.5001 0.02
           2.00   0.02
* End of table

* List relative death rates of stems [kg/kg/d] as function of dev. stage [0..2 -, R]:
*           DVS   RDRS      (maximum 15 records)
  RDRSTB = 0.00   0.00
           1.50   0.00
           1.5001 0.02
           2.00   0.02
* End of table
**********************************************************************************************

**********************************************************************************************
* Section 10: Crop water use
*
 HLIM1  =   -10.0 ! No water extraction at higher pressure heads, [-100..100 cm, R]
 HLIM2U =   -25.0 ! h below which optimum water extr. starts for top layer, [-1000..100 cm, R]
 HLIM2L =   -25.0 ! h below which optimum water extr. starts for sub layer, [-1000..100 cm, R]
 HLIM3H =  -320.0 ! h below which water uptake red. starts at high Tpot, [-10000..100 cm, R]
 HLIM3L =  -600.0 ! h below which water uptake red. starts at low  Tpot, [-10000..100 cm, R]
 HLIM4  = -8000.0 ! No water extraction at lower pressure heads, [-16000..100 cm, R]
 RSC    =   70.0  ! Minimum canopy resistance, [0..1000 s/m, R]
 ADCRH  =    0.5  ! Level of high atmospheric demand, [0..5 cm/d, R]
 ADCRL  =    0.1  ! Level of low atmospheric demand, [0..5 cm/d, R]
**********************************************************************************************

**********************************************************************************************
* Section 11: Salt stress
*
  ECMAX  =    2.0 ! ECsat level at which salt stress starts, [0..20 dS/m, R]
  ECSLOP =    0.0 ! Decline of rootwater uptake above ECMAX, [0..40 %/dS/m, R]
**********************************************************************************************

**********************************************************************************************
* Section 12: Interception
*
 COFAB  =    0.25 ! Interception coefficient Von Hoyningen-Hune and Braden, [0..1 cm, R]
**********************************************************************************************

**********************************************************************************************
* Section 13: Root density distribution and root growth
*
* List relative root density [0..1 -, R], as function of rel. rooting depth [0..1 -, R]:
*         Rdepth Rdensity  (maximum 11 records)
  RDCTB =    0.0      1.0
             1.0      1.0
* End of table

  RDI  =    10.0  ! Initial rooting depth, [0..1000 cm, R]
  RRI  =     1.2  ! Maximum daily increase in rooting depth, [0..100 cm/d, R]
  RDC  =   125.0  ! Maximum rooting depth crop/cultivar, [0..1000 cm, R]

* End of File ********************************************************************************
```

File wheatd.crop: detailed crop growth, section 9 - 13

4.9 Detailed grass growth (*.crp)

This grass crop model is a specialised form of the WOFOST crop model, ignoring some of the parameters of the detailed crop model. The following assumptions where made with respect to the grass cover:

– the grass consists of the species perennial ryegrass;
– the sward is regularly mowed and remains vegetative;
– no grazing by cattle takes place;
– the grassland is permanent.

As the grass grows continuously, the crop development stage can not be used as time variable. Instead, the daynumber is used to define the change of variables over time. It also means that the rate of development can be ignored and subsequently the parameters defining this development. The grass model uses only the second growth stage, which is the source (assimilates) limited growth stage.

4.9.1 Section 1: Initial values

The growth parameters needed are the initial crop weight, the leaf area index and the maximum relative increase in LAI.

```
**********************************************************************************
* Filename: grass.CRP
* Contents: SWAP 2.0 - Crop data of detailed grass model
**********************************************************************************
*c Comment area:
*c
*c
**********************************************************************************


**********************************************************************************
* Section 1: Initial values
*
  TDWI   = 1000.0 ! Initial total crop dry weight, [0..10000 kg/ha, R]
  LAIEM  =   0.63 ! Leaf area index at emergence, [0..10 m2/m2, R]
  RGRLAI = 0.0070 ! Maximum relative increase of LAI per day, [0..1 m2/m2/d, R]
**********************************************************************************
```

File grass.crp: detailed crop growth, section 1

4.9.2 Section 2: Green surface area

In the second (assimilates limited) growth stage the maximum increase in leaf area index is determined by the specific leaf area. The specific leaf area of a grass crop can differ depending on the season. SWAP allows for introduction of a curve describing the specific leaf area in up to 15 data points as a function of the daynumber.

To determine total assimilation it is necessary to know the green area of the stems since these can also absorb radiation.

Under optimal conditions (constant 35 °C) leaves have a certain life span. Lower temperatures limit the life span of the leaves. Next to the optimal temperature of 35 °C, a lower threshold temperature, which is crop specific, should be entered.

4.9.3 Section 3: Assimilation

This section contains the parameters needed to calculate the assimilation rate from the solar radiation data. Detailed information about the assimilation calculations can be found in Par. 7.3 through 7.5 of Van Dam et al (1997). The extinction coefficients and light use efficiency are needed to calculate a potential gross assimilation rate for the crop. The assimilation rate is than reduced by either the phenological stage of the crop, the average daytime temperature or a low minimum temperature at night when the assimilates are transformed.

In case of a grass crop, the maximum CO2 assimilation rate (AMAX) is a function of the daynumber. The user can enter data (up to 15 data pairs) to characterise this relationship. The reduction factor (TMPF) based on average daily temperature accounts for sub-optimum temperatures. The input allows for a relationship, between TMPF and daynumber, defined in up to 15 data pairs. The influence of a low minimum night temperature on the reduction factor of AMAX (TMNF) also can be defined by a relationship of up to 15 data pairs.

4.9.4 Section 4: Conversion of assimilates into biomass

Conversion into dry matter in case of a grass ignores storage organs. The assimilates are transformed into structural biomass after subtraction of respiration for maintenance. Depending on the product formed, the efficiency of the conversion of primary photosynthates to structural plant material varies. Efficiencies are crop specific and should be specified in this section.

4.9.5 Section 5: Maintenance respiration

An increase in temperature causes an increase in maintenance respiration. Generally a 10 °C temperature increase causes maintenance respiration to increase by a factor 2.

Respiration depends on relative maintenance coefficients of the specific crop organs. These coefficients are proportional to the dry weights of the plant organs.

Senescence will decrease respiration. In case of a grass crop, the reduction factor (RFSE) can be dependent on the season. The user can enter up to 15 data pairs to define the relationship between RFSE and daynumber.

4.9.6 Section 6: Partitioning

The partitioning of the produced structural plant material to the different plant organs is defined by partitioning factors (FR, FL, FS), which each depend on the season (i.e. daynumber). Note that the sum of the partitioning factors of leaves and stems should equal 1.0 at any development stage (see Par. 7.8 of Van Dam et al, 1997) !

4.9.7 Section 7: Death rates

Here the user needs to define the death rate due to water and/or salinity stress. The user can specify a death rate of the roots (RDRR) and stems (RDRS) as a function of the daynumber (up to 15 data pairs). The death rate of the leaves is somewhat more complicated (see paragraph 7.9 of Van Dam et al, 1997), and has already partly been in section 2.

4.9.8 Section 8: Crop water use

Both the water and the salinity stress will limit the potential transpiration of the crop. SWAP assumes that the reduction factors due to water and salinity stress are multiplicative.

The user should enter the pressure heads defining the root water extraction function. The soil water potential stress relationship (as depicted in fig 2.2 of Van Dam et al, 1997) is used to calculate the water stress of the crop. For this relationship the user should specify the upper and lower limits of the root water extraction function.

If the Penman-Monteith equation is used, the user needs to supply the minimum canopy resistance RSC.

Under high atmospheric demand transpiration might decrease earlier than under low atmospheric demand. SWAP assumes a linear relationship between the potential transpiration rate and the threshold pressure head HLIM3.

4.9.9 Section 9: Salt stress

Reduction of water uptake due to salt stress needs input of a maximum salt tolerance value (EC value below which no salt stress occurs) and the slope of the EC and root water uptake reduction curve (see Par. 2.3 of Van Dam et al, 1997).

4.9.10 Section 10: Interception

The precipitation interception coefficient is used to calculate the amount of interception with the Braden (1985) concept. At increasing precipitation amounts, the interception asymptotically reaches the value COFAB*LAI cm, where LAI is the leaf area index.

4.9.11 Section 11: Root density distribution and root growth

The user may enter up to 15 data pairs to define the relative root density distribution as a function of the relative rooting depth. Any unit for the root density can be used; SWAP will normalise the root density distribution.

Root growth is calculated rather straightforward. The user needs to define the initial rooting depth, the maximum daily increase and the maximum rooting depth. The daily increase is equal to the maximum daily increase unless too few assimilates are available or the maximum rooting depth is reached.

```
**********************************************************************************
* Section 2: Green surface area
*
* List specific leaf area [ha/kg, R] as function of time [0..366 d, R] :
*         TIME     SLA    (maximum 15 records)
  SLATB =  1.0  0.0015
          80.0  0.0015
         300.0  0.0020
         366.0  0.0020
* End of table

  SSA    =  0.0   ! Specific stem area, [0..1 ha/kg, R]
  SPAN   = 30.0   ! Life span of leaves at optimum conditions, [0..366 d, R]
  TBASE  =  0.0   ! Lower threshold temperature for ageing of leaves, [-10..30 C, R]
**********************************************************************************


**********************************************************************************
* Section 3: Assimilation
*
  KDIF   =  1.00  ! Extinction coefficient for diffuse visible light, [0..2 -, R]
  KDIR   =  0.75  ! Extinction coefficient for direct visible light, [0..2 -, R]
  EFF    =  0.50  ! Light use efficiency of single leaf, [0..10 kg/ha/hr/(Jm2s), R]

* List max. CO2 assimilation rate [kg/ha/hr, R] as function of time [0..366 d, R]:
*          TIME   AMAX    (maximum 15 records)
  AMAXTB =  1.0   40.0
           95.0   40.0
          200.0   35.0
          275.0   25.0
          366.0   25.0
* End of table

* List reduction factor of AMAX [-, R] as function of average day temp. [-10..50 C, R]:
*           ADT   TMPF    (maximum 15 records)
  TMPFTB = 0.00   0.00
           5.00   0.70
          15.00   1.00
          25.00   1.00
          40.00   0.00
* End of table

* List reduction factor of AMAX [-, R] as function of minimum day temp. [-10..50 C, R]:
*           MDT   TMNF    (maximum 15 records)
  TMNFTB = 0.00   0.00
           4.00   1.00
* End of table
**********************************************************************************


**********************************************************************************
* Section 4: Conversion of assimilates into biomass
*
  CVL    = 0.685  ! Efficiency of conversion into leaves, [0..1 kg/kg, R]
  CVR    = 0.694  ! Efficiency of conversion into roots,  [0..1 kg/kg, R]
  CVS    = 0.662  ! Efficiency of conversion into stems,  [0..1 kg/kg, R]
**********************************************************************************


**********************************************************************************
* Section 5: Maintenance respiration
*
  Q10    =  2.0   ! Rel. increase of respiration rate with temperature, [0..5 /10 C, R]
  RML    =  0.030 ! Rel. maintenance respiration rate of leaves, [0..1 kgCH2O/kg/d, R]
  RMR    =  0.015 ! Rel. maintenance respiration rate of  roots, [0..1 kgCH2O/kg/d, R]
  RMS    =  0.015 ! Rel. maintenance respiration rate of  stems, [0..1 kgCH2O/kg/d, R]

* List reduction factor of senescence [-, R] as function of time [0..366 d, R]:
*           TIME  RFSE    (maximum 15 records)
  RFSETB =   1.0  1.00
           366.0  1.00
* End of table
**********************************************************************************
```

File grass.crp: sections 2-5

```
**********************************************************************************
* Section 6: Partitioning
*
* List fraction of total dry matter increase partitioned to the roots [kg/kg, R]
* as function of time [0..366 d, R]:
*        TIME     FR      (maximum 15 records)
  FRTB =  1.0   0.30
        366.0   0.30
* End of table

* List fraction of total above ground dry matter incr. part. to the leaves [kg/kg, R]
* as function of time [0..366 d, R]:
*        TIME     FL      (maximum 15 records)
  FLTB =  1.0   0.60
        366.0   0.60
* End of table

* List fraction of total above ground dry matter incr. part. to the stems [kg/kg, R]
* as function of time [0..366 d, R]:
*        TIME     FS      (maximum 15 records)
  FSTB =  1.0   0.40
        366.0   0.40
* End of table
**********************************************************************************

**********************************************************************************
* Section 7: Death rates
*
  PERDL = 0.050 ! Maximum rel. death rate of leaves due to water stress, [0..3 /d, R]

* List relative death rates of roots [kg/kg/d] as function of time [0..366 d, R]:
*          TIME   RDRR      (maximum 15 records)
  RDRRTB =  1.0   0.00
          366.0   0.00
* End of table

* List relative death rates of stems [kg/kg/d] as function of time [0..366 d, R]:
*          TIME   RDRS      (maximum 15 records)
  RDRSTB =  1.0   0.00
          366.0   0.00
* End of table
**********************************************************************************

**********************************************************************************
* Section 8: Crop water use
*
 HLIM1  =   -10.0 ! No water extraction at higher pressure heads, [-100..100 cm, R]
 HLIM2U =   -25.0 ! h below which optimum water extr. starts for top layer, [-1000..100 cm, R]
 HLIM2L =   -25.0 ! h below which optimum water extr. starts for sub layer, [-1000..100 cm, R]
 HLIM3H =  -200.0 ! h below which water uptake red. starts at high Tpot, [-10000..100 cm, R]
 HLIM3L =  -800.0 ! h below which water uptake red. starts at low  Tpot, [-10000..100 cm, R]
 HLIM4  = -8000.0 ! No water extraction at lower pressure heads, [-16000..100 cm, R]
 RSC    =   70.0  ! Minimum canopy resistance, [0..1000 s/m, R]
 ADCRH  =    0.5  ! Level of high atmospheric demand, [0..5 cm/d, R]
 ADCRL  =    0.1  ! Level of low atmospheric demand, [0..5 cm/d, R]
**********************************************************************************

**********************************************************************************
* Section 9: Salt stress
*
  ECMAX  =    2.0 ! ECsat level at which salt stress starts, [0..20 dS/m, R]
  ECSLOP =    0.0 ! Decline of rootwater uptake above ECMAX, [0..40 %/dS/m, R]
**********************************************************************************

**********************************************************************************
* Section 10: Interception
*
 COFAB  =    0.25 ! Interception coefficient Von Hoyningen-Hune and Braden, [0..1 cm, R]
**********************************************************************************

**********************************************************************************
* Section 11: Root density distribution and root growth
*
* List relative root density [0..1 -, R], as function of rel. rooting depth [0..1 -, R]:
*         Rdepth Rdensity  (maximum 11 records)
  RDCTB =    0.0      1.0
             1.0      1.0
* End of table

  RDI  =    50.0  ! Initial rooting depth, [0..1000 cm, R]
  RRI  =     0.0  ! Maximum daily increase in rooting depth, [0..100 cm/d, R]
  RDC  =    50.0  ! Maximum rooting depth crop/cultivar, [0..1000 cm, R]

* End of file ********************************************************************
```

File grass.crp: detailed grass growth section 6-11

4.10 Simple crop growth (*.crp)

The simple crop model is useful when crop growth does not need to be simulated or when crop growth input data are insufficient. The simple crop growth model represents a green canopy that intercepts precipitation, transpires and shades the ground.
To facilitate the user in making choices when applying simple crop growth a flowchart is given in figure 4. The development stage of the crop can be either controlled by the temperature sum, or can be linear in time (section 1). Instead of leaf area index, soil cover fraction may be used to divide potential evapotranspiration into potential transpiration and potential evaporation (section 3). Aerodynamic properties (section 4) are used to calculate potential transpiration. If the reference evapotranspiration is input (see also par. 4.2.3 and 4.3) then crop factors may be used. If daily meteorological data are used as input then either crop factors of crop height may be used to determine potential transpiration.

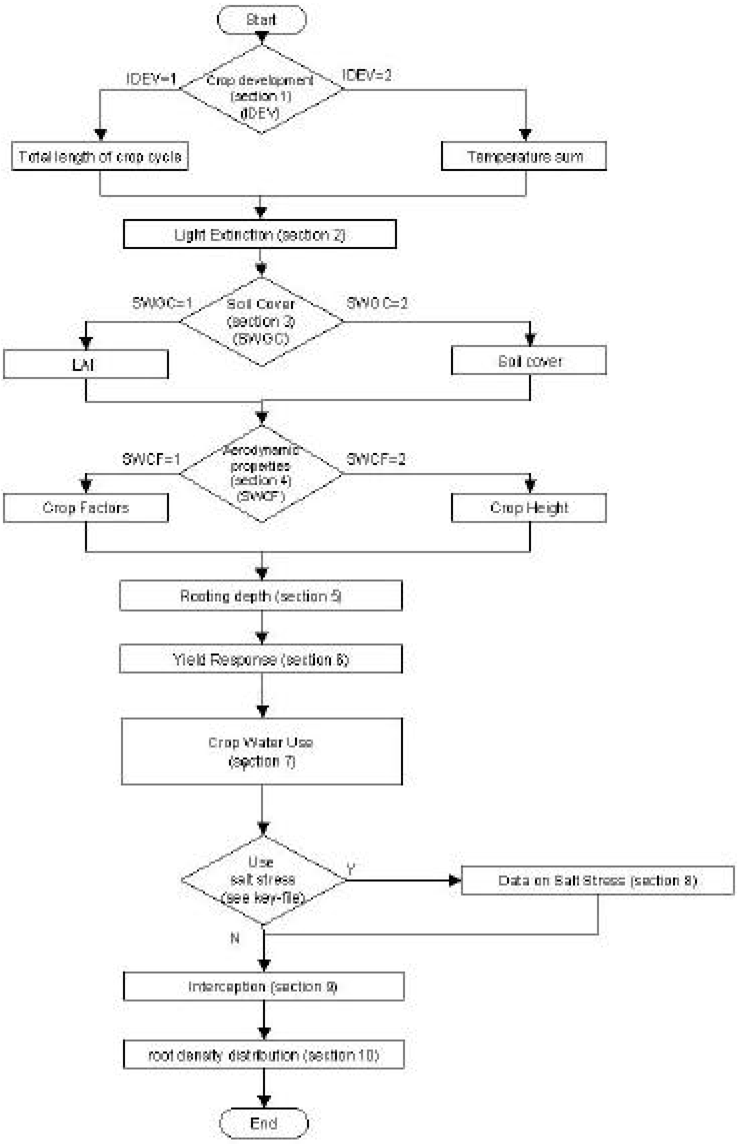


Fig. 4. Flow chart for input data on simple crop growth

4.10.1 Section 1: Crop development

Crop development can be either modelled linearly (fixed length of the crop cycle) or can be controlled by the temperature sum (variable length of the crop cycle). In the case of a fixed crop cycle, only the toal length of the crop cycle needs to be entered. In the case of a variable length of the crop cycle, different temperature sums need to be entered.

4.10.2 Section 2: Light extinction

The extinction coefficients are needed to calculate the amount of light, which reaches the leaves, and the soil surface, which in turn determines the rate of assimilation and soil evaporation (see also Van Dam et al (1997), page 74). These coefficients are not needed if the soil cover fraction is used to partition potential transpiration and potential evaporation.

```
**********************************************************************************
* Filename: MaizeS.CRP
* Contents: SWAP 2.0 - Crop data of simple model
**********************************************************************************
*c Comment area:
*c
*c Case: Water and solute transport in the Hupsel area,
*c       a catchment in the eastern part of the Netherlands
*c
*c Example of the User's Guide: reference situation
*c
*c A set of input data to explore SWAP
**********************************************************************************


**********************************************************************************
* Section 1: Crop development
*
  IDEV = 1   ! Length of crop cycle: 1 = fixed, 2 = variable

* If IDEV = 1, specify:
  LCC  = 168      ! Length of crop cycle [1..366 days, I]

* If IDEV = 2, specify:
  TSUMEA = 1050.0 ! Temperature sum from emergence to anthesis, [0..10000 C, R]
  TSUMAM = 1000.0 ! Temperature sum from anthesis  to maturity, [0..10000 C, R]
  TBASE  = 0.0    ! Start value of temperature sum, [-10..20 C, R]
**********************************************************************************


**********************************************************************************
* Section 2: Light extinction
*
  KDIF   =  0.6   ! Extinction coefficient for diffuse visible light, [0..2 -, R]
  KDIR   =  0.75  ! Extinction coefficient for direct  visible light, [0..2 -, R]
**********************************************************************************
```

File maizeS.crp: simple crop growth, sections 1 – 2

4.10.3 Sections 3: LAI or soil cover

To divide potential evapotranspiration over the potential (crop) transpiration and potential (soil) evaporation the user should specify either the leaf area index (LAI) or the soil cover fraction (SC) as a function of development stage (DVS).

4.10.4 Section 4: Crop factor or crop height

If the reference evapotranspiration is input (see also par. 4.2.3 and 4.3) then crop factors may be used. If daily meteorological data are used as input then either crop factors of crop height may be used to determine potential transpiration.

4.10.5 Section 5: Rooting depth

Rooting depth (RD) is given as a function of DVS for a maximum of 36 data pairs.

4.10.6 Section 6: Yield response

The yield response factor (KY) determines at each growing stage the relationship between the relative yield and the relative transpiration (defined as the ratio of the actual over the potential transpiration). In case of a linear relation between the relative crop yield and the relative transpiration, or when no information is available for the yield response factor as a function of DVS, specify KY = 1 for $0 \leq DVS \leq 2$.

4.10.7 Section 7: Crop water use

Both the water and the salinity stress will limit the potential transpiration of the crop. SWAP assumes that the reduction factors due to water and salinity stress are multiplicative.

The user should enter the pressure heads defining the root water extraction function. The soil water potential stress relationship (as depicted in fig 2.2 of Van Dam et al, 1997) is used to calculate the water stress of the crop. For this relationship the user should specify the upper and lower limits of the root water extraction function.

The ratio of potential crop evapotranspiration rate to reference evapotranspiration rate under full soil cover conditions needs to be entered if the user wants to use ETref values instead of the Penman-Monteith equation. This value is equal to the crop factor for full soil cover.

If the Penman-Monteith equation is used, the user needs to supply the minimum canopy resistance RSC.

Under high atmospheric demand transpiration might decrease earlier than under low atmospheric demand. SWAP assumes a linear relationship between the potential transpiration rate and the threshold pressure head HLIM3.

4.10.8 Section 8: Salt stress

Reduction of water uptake due to salt stress needs input of a maximum salt tolerance value (EC value below which no salt stress occurs) and the slope of the EC and root water uptake reduction curve (see Par. 2.3 Van Dam et al, 1997).

4.10.9 Section 9: Interception

The precipitation interception coefficient is used to calculate the amount of interception with the Braden (1985) concept. At increasing precipitation amounts, the interception asymptotically reaches the value COFAB*LAI cm, where LAI is the leaf area index.
Note: If the soil cover fraction(SC) is used as input (par. 4.10.3), then LAI for the interception-calculations will be derived from SC, according to Van Dam et al (1997) page 75, as: LAI = SC/3.

4.10.10 Section 10: Root density distribution and root growth

The user may enter up to 11 data pairs to define the relative root density distribution as a function of the relative rooting depth. Any unit for the root density can be used, SWAP will normalise the root density distribution, such that the integral of root density times depth over the rootzone equals one.

Root growth is calculated rather straightforward. The user needs to define the initial rooting depth, the maximum daily increase and the maximum rooting depth. The daily increase is equal to the maximum daily increase, unless too few assimilates are available or the maximum rooting depth is reached.

```
**********************************************************************************************
* Section 3: Leaf area index or soil cover fraction
*
  SWGC = 1 ! choice between LAI [=1] or soil cover fraction [=2]
*
* If SWGC = 1, list leaf area index [0..12 ha/ha, R],    as function of dev. stage [0..2 -,R]:
* If SWGC = 2, list soil cover fraction [0..1 m2/m2, R], as function of dev. stage [0..2 -,R]:
*        DVS   LAI or SCF  ( maximum 36 records)
  GCTB =
        0.00   0.05
        0.30   0.14
        0.50   0.61
        0.70   4.10
        1.00   5.00
        1.40   5.80
        2.00   5.20
* End of table
**********************************************************************************************

**********************************************************************************************
* Section 4: crop factor or crop height
*
  SWCF = 2 ! choice between crop factor [=1] or crop height [=2]
*
* If SWCF = 1, list crop factor [0.5..1.5, R],   as function of dev. stage [0..2 -,R]:
* If SWCF = 2, list crop height [0..1000 cm, R], as function of dev. stage [0..2 -,R]:
*
*        DVS   CF or CH   (maximum 36 records)
  CFTB = 0.0     1.0
         0.3    15.0
         0.5    40.0
         0.7   140.0
         1.0   170.0
         1.4   180.0
         2.0   175.0
* End of table
**********************************************************************************************

**********************************************************************************************
* Section 5: rooting depth
*
* List rooting depth [0..1000 cm, R], as a function of development stage [0..2 -,R]:
*        DVS   RD    (maximum 36 records)
  RDTB =
        0.00    5.00
        0.30   20.00
        0.50   50.00
        0.70   80.00
        1.00   90.00
        2.00  100.00
* End of table
**********************************************************************************************

**********************************************************************************************
* Section 6: yield response
*
* List yield response factor [0..5 -,R], as function of development stage [0..2 -,R]:
*        DVS   KY   (maximum 36 records)
  KYTB =
        0.00   1.00
        2.00   1.00
* End of table
**********************************************************************************************
```

File maizeS.crp: simple crop growth: sections 3 - 6

```
**********************************************************************************************
* Section 7: crop water use
*
 HLIM1  =     -15.0 ! No water extraction at higher pressure heads, [-100..100 cm, R]
 HLIM2U =     -30.0 ! h below which optimum water extr. starts for top layer, [-1000..100 cm, R]
 HLIM2L =     -30.0 ! h below which optimum water extr. starts for sub layer, [-1000..100 cm, R]
 HLIM3H =    -325.0 ! h below which water uptake red. starts at high Tpot, [-10000..100 cm, R]
 HLIM3L =    -600.0 ! h below which water uptake red. starts at low Tpot, [-10000..100 cm, R]
 HLIM4  =   -8000.0 ! No water extraction at lower pressure heads, [-16000..100 cm, R]
 RSC    =      70.0 ! Minimum canopy resistance [0..1000 s/m, R]
 ADCRH  =       0.5 ! Level of high atmospheric demand, [0..5 cm/d, R]
 ADCRL  =       0.1 ! Level of low atmospheric demand,  [0..5 cm/d, R]
**********************************************************************************************

**********************************************************************************************
* Section 8: salt stress
*
  ECMAX  =       2.0 ! ECsat level at which salt stress starts, [0..20 dS/m, R]
  ECSLOP =       0.0 ! Decline of rootwater uptake above ECMAX [0..40 %/dS/m, R]
**********************************************************************************************

**********************************************************************************************
* Section 9: interception
*
  COFAB  =      0.25 ! Interception coefficient Von Hoyningen-Hune and Braden, [0..1 cm, R]
**********************************************************************************************

**********************************************************************************************
* Section 10: Root density distribution and root growth
*
* List relative root density [0..1 -, R], as function of rel. rooting depth [0..1 -, R]:
*        Rdepth Rdensity  (maximum 11 records)
  RDCTB =
       0.00   1.00
       1.00   0.00
* End of table

* End of file ********************************************************************************
```

File maizeS.crp: simple crop growth: sections 7 - 10

4.11 Soil water and profile (*.swa)

4.11.1 Section 1: Ponding

The maximum ponding layer thickness [cm] determines which water layer can be present on top of the soil surface before runoff starts.

4.11.2 Section 2: Soil evaporation

The conversion of potential soil evaporation from potential evaporation can be multiplied with a coefficient for soil evaporation. This may be appropriate for instance if one applies the simple crop growht model (par. 4.10) with reference evapotranspiration as input (par. 4.3). For such a case the given reference evapotranspiration may be corrected for periods where the crop is absent or small. One value can be given within the ranges 0.5 and 1.5.

SWAP calculates actual soil evaporation using the soil hydraulic functions in case of a dry soil. In case of a wet soil, actual evaporation equals potential evaporation. To calculate the actual evaporation accurately the thickness of the top compartment should not be too large (see for detailed information Van Dam et al., 1997, par. 2.2 and 6.8). The manual suggests a thickness of 1 cm near the soil surface.

Since the soil evaporation could be overestimated using ordinary soil hydraulic functions, SWAP allows the use of two alternative empirical functions. Since these functions are empirical, the parameters are soil and location specific and will need to be determined by the user. SWAP will determine the actual evaporation rate by taking the minimum value of E_{max} (from soil hydraulic functions), E_p (potential from meteo data) and the evaporation rates according to the empirical functions (if selected by the user).

4.11.3 Section 3: Time discretization of Richards' equation

To solve the numerical scheme accurately and efficiently, the user should define minimum and maximum time steps. The time steps are defined as fractions of a day. The program will look for the optimal time step between the defined limits, taking the number of iterations to reach convergence as a criterium. Making the time step range too large could lead to instability, while making it too small will increase the calculation time substantially.

The stop criterium for the iteration procedure is defined between 1E-05 and 0.1 (cm^3 cm^{-3}) and basically defines convergence. Choosing it too large could introduce errors, while choosing it too small will increase the calculation time substantially. The user should check the mass balance error in the soil water output file (*.WBA) to determine if the error is acceptable.

The user can choose two types of implicit schemes:
1. Richards equation is solved twice per time step. For very simple problems, under steady state or slowly changing conditions, this might be appropriate.
2. Richards equation is solved until convergence. This is the recommended procedure for most transient unsaturated flow problems.

```
**********************************************************************************
* Filename: Hupsel.SWA
* Contents: SWAP 2.0 - Soil water and profile data
**********************************************************************************
*c Comment area:
*c
*c Case: Water and solute transport in the Hupsel area,
*c       a catchment in the eastern part of the Netherlands
*c
*c Example of the User's Guide: reference situation
*c
*c A set of input data to explore SWAP
**********************************************************************************

**********************************************************************************
* Section 1: Ponding
*
 PONDMX = 0.2  ! Maximum thickness of ponding water layer, [0..1000 cm, R]
**********************************************************************************


**********************************************************************************
* Section 2: Soil evaporation
*
  SWCFBS = 0   ! Switch for use of coefficient (CFBS) for soil evaporation [Y=1, N=0]
*               0 = CFBS is not used
*               1 = CFBS used to calculate ES0 from ET0, ETR or ESO
*
* If SWCFBS = 1 then specify CFBS, else a dummy value may entered for CFBS:
  CFBS   = 1.0 ! Coefficient for soil evaporation [0.5..1.5 -, R]
*
 SWREDU = 1    ! Switch, method for reduction of soil evaporation:
*              0 = reduction to maximum Darcy flux
*              1 = reduction to maximum Darcy flux and to maximum Black (1969)
*              2 = reduction to maximum Darcy flux and to maximum Bo/Str. (1986)

 COFRED = 0.35 ! Soil evaporation coefficient of Black, [0..1 cm/d1/2, R],
*                or Boesten/Stroosnijder, [0..1 cm1/2, R]
 RSIGNI =  0.5 ! Minimum rainfall to reset models Black and Bo/Str., [0..1 cm/d, R]
**********************************************************************************

**********************************************************************************
* Section 3: Time discretization of Richards' equation
*
 DTMIN  = 1.0E-5 ! Minimum timestep, [1.E-8..0.1 d, R]
 DTMAX  =    0.2 ! Maximum timestep, [ 0.01..0.5 d, R]
 SWNUMS =      2 ! Type of implicit scheme:
*                  1 = Richards equation is solved twice per time step
*                  2 = Richards equation is solved until convergence (use in general)
 THETOL =  0.001 ! Maximum dif. water content between iterations, [1.E-5..0.01 cm3/cm3]
**********************************************************************************
```

File: hupsel.swa, example of a file with soil water and profile data, section 1 - 3

4.11.4 Section 4: Spatial discretization

SWAP allows for the definition of up to 5 soil layers. Additionally, the soil is subdivided in a maximum of 40 compartments, which are used in the finite difference scheme. Minimising the number of compartments will decrease calculation time, but might increase the mass balance error.

For each soil layer, the bottom compartment number should be defined. The soil layers are numbered from top to bottom. For each compartment the thickness (in cm) should be defined. Note that for accurate calculation of top boundary fluxes, the compartment thickness should be small (~ 1 cm) near the soil surface.

4.11.5 Section 5: Soil hydraulic functions and maximum rooting depth

Specify for each soil layer a file with soil hydraulic functions, which are described in Par. 4.12. Note that no file extension should be entered.

The depth at which rooting is limited by the soil profile should be entered here. The program will also check the maximum rooting depth of the crop and will use the minimum of the two maximum depths as boundary when simulating root growth.

4.11.6 Section 6: Hysteresis of soil water retention function

In SWAP hysteresis only affects the water retention function. The hydraulic conductivity as function of soil water content is considered uniquely defined. SWAP uses the method of Scott et al. (1983) to simulate hysteresis. If hysteresis is simulated, the user should define either initial condition wetting, or initial condition drying. If the soil is initially dry and is getting wet during the simulation, the simulation should start from the initial condition wetting. Alternatively, if the initial condition is wet (for instance in winter, or after a rainstorm) the initial condition for hysteresis should be drying.

A minimum head difference to change from wetting to drying [cm] at a soil node should be specified. This parameter is introduced to prevent the program from quickly swapping from a wetting to a drying curve if small changes in the pressure head, in a direction opposite to the previous direction, occur.

If hysteresis is chosen by the user, the hydraulic functions should be defined with Mualem-van Genuchten parameters in the soil hydraulic function file, *.SOL. If hysteresis applies, similar media scaling (section 7) or preferential flow due to immobile water (section 8) can not be applied.

4.11.7 Section 7: Similar media scaling of soil hydraulic functions

This option allows the scaling of the Mualem-van Genuchten parameters of the soil hydraulic function to simulate spatial variability following Miller and Miller (1956). For each defined scaling factor SWAP will run another simulation, using the scaled soil hydraulic functions. These runs are thus examples of parallel runs. If this option is chosen, a maximum period of one year can be simulated with SWAP. SWAP allows for the definition of 30 different scaling factors, implying 30 different sub-runs.

The user should define the number of repetitions (or scaling factors) and soil layers which should be scaled. The soil layers are counted from the soil surface downwards. For each repetition the user should specify a scaling factor, of which 1.0 means: 'not scaled'.

If scaling is chosen by the user, the soil hydraulic functions should be defined with the Mualem-van Genuchten parameters in the soil hydraulic function files, *.SOL. If scaling applies, hysteresis of the retention function (section 6) or preferential flow due to immobile water (section 8) can not be applied.

```
**********************************************************************************
* Section 4: Spatial discretization
*
 NUMLAY = 2      ! Number of soil layers, [1..5, I]
 NUMNOD = 34     ! number of soil compartments, [1..40, I]

* List compartment number at bottom of each soil layer (max 5), [1..40, I]:
  BOTCOM =    14     34

* List thickness of each soil compartment (max 40), [0..500 cm, R]:
  DZ =
    1.0    1.0    1.0    1.0    1.0    1.0    1.0    1.0    1.0    1.0
    5.0    5.0    5.0    5.0    5.0    5.0    5.0    5.0    5.0    5.0
   10.0   10.0   10.0   10.0   10.0   10.0   10.0   10.0   10.0   10.0
   10.0   10.0   10.0   10.0
**********************************************************************************


**********************************************************************************
* Section 5: Soil hydraulic functions and maximum rooting depth
*
* Specify for each soil layer (max 5) the hydr. function file without .SOL ext., [A8]
  SOLFIL =     'Sandt'      'Sands'
*
* Specify for each soil layer (max. 5) the soil texture (g/g mineral parts) and
* the organic matter content (g/g dry soil)
*    PSAND    PSILT    PCLAY    ORGMAT
      0.80     0.15     0.05     0.100
      0.78     0.14     0.08     0.012
* End of table
*
  RDS  = 200.0   ! Maximum rooting depth allowed by the soil profile, [1..1000 cm, R]
**********************************************************************************


**********************************************************************************
* Section 6: Hysteresis of soil water retention function
*
  SWHYST = 0   ! Switch, hysteresis:
*               0 = no hysteresis
*               1 = hysteresis, initial condition wetting
*               2 = hysteresis, initial condition drying

* If SWHYST=1 or 2, specify:
  TAU = 0.2    ! Minimum pressure head difference to change wetting-drying, [0..1 cm, R]
**********************************************************************************


**********************************************************************************
* Section 7: Similar media scaling of soil hydraulic functions
*
  SWSCAL = 0 ! Switch, similar media scaling [Y=1, N=0]

* If SWSCAL = 1, specify:
  NSCALE = 3 ! Number of runs, [1..30, I]
  ISCLAY = 2 ! Number of soil layer to which scaling is applied, [1..5, I]

* List scaling factor of each run (max. 30), [0..100, R]
  FSCALE =
  0.45   1.00   2.50   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
**********************************************************************************
```

File: hupsel.swa, example of a file with soil water and profile data, section 4 – 7

4.11.8 Section 8: Preferential flow due to immobile water

SWAP allows for simulation of preferential flow due to unstable wetting fronts, e.g. in case of water repellent soils. The soil is divided in a mobile (or transport) domain and an immobile (or resident) domain. Exchange of solutes between the two domains is governed by the exchange of water and diffusion of solutes. The solute exchange coefficient for the preferential flow (if applicable) should be defined in file *.SLT, section 5. The mobile fraction of the soil is defined in this section.

In water repellent soils the mobile soil fraction may depend on the water content of the soil. SWAP assumes a linear relationship between log(-h) and the mobile soil fraction. The user should specify the log(-h) and the mobile soil fraction (FM) for two data points to define this linear relationship. If the user wants to simulate a situation in which the mobile soil fraction is not dependent on the soil water content, of course a constant relationship can be defined. Additionally, the constant volumetric water content in the immobile fraction should be specified, since this value can be substantially different from the water content in the mobile soil fraction.
If preferential flow is selected by the user, the soil hydraulic functions should be defined with the Mualem-van Genuchten parameters in the soil hydraulic function files, *.SOL. If preferential flow applies, hysteresis of the retention function (section 6) or scaling of the soil hydraulic functions (section 7) can not be applied.

4.11.9 Section 9: Preferential flow due to soil cracks

SWAP employs the clay shrinkage characteristic for the simulation of soil crack formation and water and solute transport in cracks. The residual shrinkage stage of the shrinkage characteristic is described by an exponential relationship. The user needs to supply three points of the relationship between moisture ratio (v) and the void ratio (e) and SWAP will determine the necessary parameters describing the entire shrinkage characteristic. The points which need to be supplied are the void ratio (e) at ν=0 (zero water content), the moisture ratio at the transition of residual to normal shrinkage (ν_1) and the structural shrinkage ν_s. See for more detail Fig. 5.2 of Van Dam et al (1997).

If the crack area at the soil surface is calculated, the crack area for infiltration might be underestimated due to the sharp water content increase close to the soil surface. This would underestimate the amount of infiltration into the cracks. To prevent this, SWAP allows calculation of the horizontal crack area for infiltration at a certain soil depth. Applications show that a depth of 5 cm below soil surface performs well.

Shrinkage might not occur in an isotropic way, meaning that all three dimensions shrink at the same rate. This is defined by the geometry factor R_s , which equals 3 in case of isotropic shrinkage. If only subsidence occurs, $R_s = 1$, in case subsidence dominates cracking $1 < R_s < 3$, in case cracking dominates subsidence $R_s > 3$.

The diameter of the soil matrix polygon determines the area of the crack walls relative to the surface area. The bypass flow rate of the crack storage water, which bypasses the soil matrix and directly flows to the drains, is calculated similar to linear reservoirs, using the exponential rate coefficient defined here. The effective lateral diffusion coefficient determines the rate of solute diffusion from the soil matrix to the bypassing water and has to be derived in the laboratory or from field measurements.

Cracks are formed if the soil water content becomes smaller than a critical value. The critical water content depends on the amount of clay and the clay mineralogy. In case of moderately to heavy clay soils, the critical water content is close to the saturated water content.

4.11.10 Section 10: Vertical distribution of drainage flux

If solute transport with lateral drainage is to be simulated the drainage flux may be partitioned over the saturated layers. If this option is not chosen, SWAP assumes that the drainage flux leaves the model at the bottom compartment. If only water flow is simulated or a relatively small section of a deep saturated profile is simulated, this assumption is realistic. However in case of solute transport and deep, non-uniform soils (see also chapter 10 in Van Dam et al, 1997) the vertical distribution of drainage fluxes in the saturated zone becomes important and should be taken into account.

If this option is chosen, anisotropy factors need to be defined for each soil layer. The anisotropy factor is the ratio of the vertical over the horizontal saturated hydraulic conductivity. The user should also specify the drain spacing in the drainage file (see Par. 4.13 or 4.14).

4.11.11 Section 11: Initial moisture condition

The user can define two types of initial moisture conditions:

1. The first possibility is to define nodal pressure heads for each compartment. This option is useful if the simulated situation starts from non-equilibrium or if no groundwater table is simulated. Note that initial pressure heads should be entered in cm, where negative numbers indicate unsaturated conditions. Unlike water contents, soil water pressure heads are continuous with depth.
2. The second possibility is to define the initial moisture conditions as an equilibrium profile with the groundwater table. In this case the nodal pressure at the groundwater table equals zero and the nodal pressure decreases linearly with height towards the soil surface. In this case the initial groundwater level needs to be specified. Note that the value specified should be negative, if the groundwater level is below the soil surface.

```
**********************************************************************************
* Section 8: Preferential flow due to soil volumes with immobile water
*
  SWMOBI = 0  ! Switch, preferential flow due to immobile water, [Y=1, N=0]

* If SWMOBI = 1, specify mobile fraction as function of log -h for each soil layer:
* PF1    first datapoint,  log -h (cm), [0..5, R]
* FM1    first datapoint,  mobile fraction (1.0 = totally mobile), [0..1, R]
* PF2    second datapoint, log -h (cm), [0..5, R]
* FM2    second datapoint, mobile fraction (1.0 = totally mobile), [0..1, R]
* Also specify volumetric water content in immobile soil volume (THETIM), [0..0.3, R]
*   PF1    FM1    PF2    FM2   THETIM
    0.0    0.4    3.0    0.4    0.02
    0.0    1.0    3.0    1.0    0.02
* End of table
**********************************************************************************

**********************************************************************************
* Section 9: Preferential flow due to soil cracks
*
  SWCRACK = 0  ! Switch, soil cracks, [Y=1, N=0]

* If SWCRACK = 1, specify:
  SHRINA = 0.53   ! Void ratio at zero water content, [0..2 cm3/cm3, R]
  MOISR1 = 1.0    ! Moisture ratio at trans. residual --> normal shrinkage [0..5 cm3/cm3, R]
  MOISRD = 0.05   ! Structural shrinkage, [0..1 cm3/cm3, R]
  ZNCRACK = -5.0  ! Depth at which crack area of soil surface is calculated [-100..0 cm, R]
  GEOMF = 3.0     ! Geometry factor (3 = isotropic shrinkage), [0..100, R]
  DIAMPOL = 40.0  ! Diameter soil matrix polygon, [0..100 cm, R]
  RAPCOEF = 0.0   ! Rate coef. bypass flow from cracks to surface water [0..10000 /d, R]
  DIFDES = 0.2    ! Effective lateral solute diffusion coefficient, [0..10000 /d, R]

* If SWCRACK = 1, specify also crit. water content of each soil layer (max. 5), [0..1, R];
* if actual water becomes smaller than critical water content, cracks are formed
  THETCR = 0.35  0.40
**********************************************************************************

**********************************************************************************
* Section 10: Vertical distribution drainage flux in saturated part soil column
*
  SWDIVD = 1 ! Switch, apply vertical distribution [Y=1, N=0]

* If SWDIVD = 1, specify anisotropy factor (vertical/horizontal saturated hydraulic
* conductivity) for each soil layer (max. 5), [0..1000 -, R] :
  COFANI =    1.0    1.0    1.0    1.0    1.0
**********************************************************************************

**********************************************************************************
* Section 11: Initial moisture condition
*
 SWINCO = 2 ! Switch, type of initial moisture condition:
*            1 = pressure head of each compartment is input
*            2 = pressure head of each compartment is in hydrostatic equilibrium with
*                initial groundwater table

* If SWINCO = 1, specify initial h (max 40), [-1.E10..1.E4 cm, R]:
  HI =
    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0

* If SWINCO = 2, specify:
  GWLI   = -75.0  ! Initial groundwater level, [-5000..100 cm, R]

* End of file *********************************************************************
```

File Hupsel.swa, example of a file with soil water and profile data, sections 8 – 11

4.12 Soil hydraulic functions (*.sol)

For each soil layer defined in the soil profile, the relations between the soil water pressure head, the soil moisture content and the unsaturated hydraulic conductivity should be specified. SWAP allows either definition of this relationship with a table, or with the Mualem-van Genuchten analytical function.

If the simulation includes hysteresis of the retention function, scaling of the soil hydraulic functions or preferential flow due to immobile water, the analytical function should be used!

If the tabular form is chosen, for each moisture content [0..1 cm3/cm3, R]) the corresponding soil water pressure head [-1.E10..0 cm, R] and unsaturated hydraulic conductivity [1.E-15..1000 cm/d, R] needs to be defined. The user should start with the lowest water content, of which the corresponding pressure head should be lower than -1.0E6 cm. Next water content increments of 0.01 should be used until the saturated water content.

If the analytical function option is chosen, the parameters of the Mualem-van Genuchten equation should be entered. The parameter COFGEN8, describing the α parameter of the main wetting curve of the soil water retention function, is only needed in case hysteresis should be simulated. The option for hysteresis is chosen in file *.SWA, section 6.

```
**********************************************************************************
* Filename: Sandt.sol
* Contents: SWAP 2.0 - Soil hydraulic functions
**********************************************************************************
*c Comment area:
*c
*c Parameters based on Staring series (Wosten et al., 1994)
**********************************************************************************


**********************************************************************************
* Section 1: Method
*
  SWPHYS = 1  ! Switch, method to describe soil hydraulic functions:
*              0 = Table
*              1 = Analytical function of Mualem - Van Genuchten (1980)
**********************************************************************************

**********************************************************************************
* Section 2: Table
*
* Specify pressure head [cm, negative] and hydraulic conductivity [cm/d] as function of
* water content [cm3/cm3];
* start with the lowest water content (corresponding pressure head should be smaller than
* -1.0E6) and use increments of 0.01 until the saturated water content:

* theta  H_theta       K_theta
  0.020 -5.658312E+06  5.678438E-10
  0.030 -3.863693E+04  3.599819E-08
    \       \             \
    /       /             /
    \       \             \
  0.430  0.000000E+00  9.650000E+00
* End of table
**********************************************************************************

**********************************************************************************
* Section 3: Analytical function of Mualem - Van Genuchten (1980)
*
  COFGEN1 =      0.01 ! Residual moisture content, [0..0.4 cm3/cm3, R]
  COFGEN2 =      0.43 ! Saturated moisture content, [0..0.95 cm3/cm3, R]
  COFGEN3 =      9.65 ! Saturated hydraulic conductivity, [0.01..1000 cm/d, R]
  COFGEN4 =    0.0227 ! Alpha main drying curve drying, [0.0001..1 /cm, R]
  COFGEN5 =    -0.983 ! Exponent in hydraulic conductivity function, [-25..25 -, R]
  COFGEN6 =     1.548 ! Parameter n, [1..5 -, R]
  COFGEN8 =    0.0454 ! Alpha main wetting curve, [0.0001..1 /cm, R]

* End of file *********************************************************************
```

File Sandt.sol, example of a file with soil hydraulic functions, sections 1 - 3

4.13 Basic drainage (*.drb)

SWAP allows for two different drainage routines. The basic drainage routine, meant for most field-scale situations and the extended drainage routine, meant for simulation of drainage at a regional level and surface water management. If the user does not want to simulate surface water, the basic drainage routine should suffice. The basic drainage routine does allow for simulation of drainage through several drainage levels, including channels, when drainage and infiltration resistances are selected. Note that in file SWAP.KEY, section 4 and 5, in case of drainage the user should already have chosen either the basic or the extended drainage routine.

4.13.1 Section 1: Method

Three methods are available to establish the drainage flux:
1. Tabular q_{drain}(gwl) relationship using a table with flux-groundwater level data pairs
2. Calculated drainage using the formulas of Hooghoudt and Ernst
3. Linear q_{drain}(gwl) relationship, which is calculated using given drainage/infiltration resistance for one or more different levels

SWAP allows for both drainage and sub-irrigation through the same system. Prior to calculating the drainage or sub-irrigation rate, it is determined whether the flow situation involves drainage, sub-irrigation or neither. No drainage or sub-irrigation will occur if both the groundwater level and the surface water level are below the drainage base. Drainage will occur if the following two conditions are met:

- the groundwater level is higher than the channel bed level;
- the groundwater level is higher than the surface water level.

Sub-irrigation can only occur if the following two conditions are met:

- the surface water level is higher than the channel bed level;
- the surface water level is higher than the groundwater level.

The maximum of the surface water level and the channel bed level will be used to calculate the drainage base.

4.13.2 Section 2: Table of drainage flux - groundwater relation

This option should be used if the relationship between q_{drain} and the groundwater level is non-linear. SWAP will linearly interpolate between the specified values. The drain spacing should be entered in [m]. The drain spacing does not need to be specified if the user did not partition the drainage flux vertically (file *.SWA, section 10).

4.13.3 Section 3: Drainage formula of Hooghoudt or Ernst

Another option to calculate drainage is to use the formulas of Hooghoudt (1940) and Ernst (1956), which calculate stationary groundwater flow from/to surface water. Five typical drainage situation can be chosen (figure 5):

1. On top of an impervious layer in a homogeneous profile
2. Above an impervious layer in a homogeneous profile
3. At the interface of a fine upper and a coarse lower soil layer
4. In the lower, more coarse soil layer
5. In the upper, more fine soil layer

A more complex drainage situation will demand an increasing number of input parameters. Most of these parameters are self-explanatory.
The geometry factor of Ernst (G_{dr} [0..100 -, R]) can be determined from van Dam et al (1997, table 8.1) and is listed below. The geometry factor depends on the ratio of the hydraulic conductivity of the bottom (K_{hbot}) and the top layer (K_{htop}). Using the relaxation method Ernst (1962) distinguished the following situations:
- $K_{hbot}/K_{htop} < 0.1$ ===> $G_{dr} = 1$;
- $0.1 < K_{hbot}/K_{htop} < 50$ ===> G_{dr} follows from Table 2;
- $50 < K_{hbot}/K_{htop}$ ===> $G_{dr} = 4$.

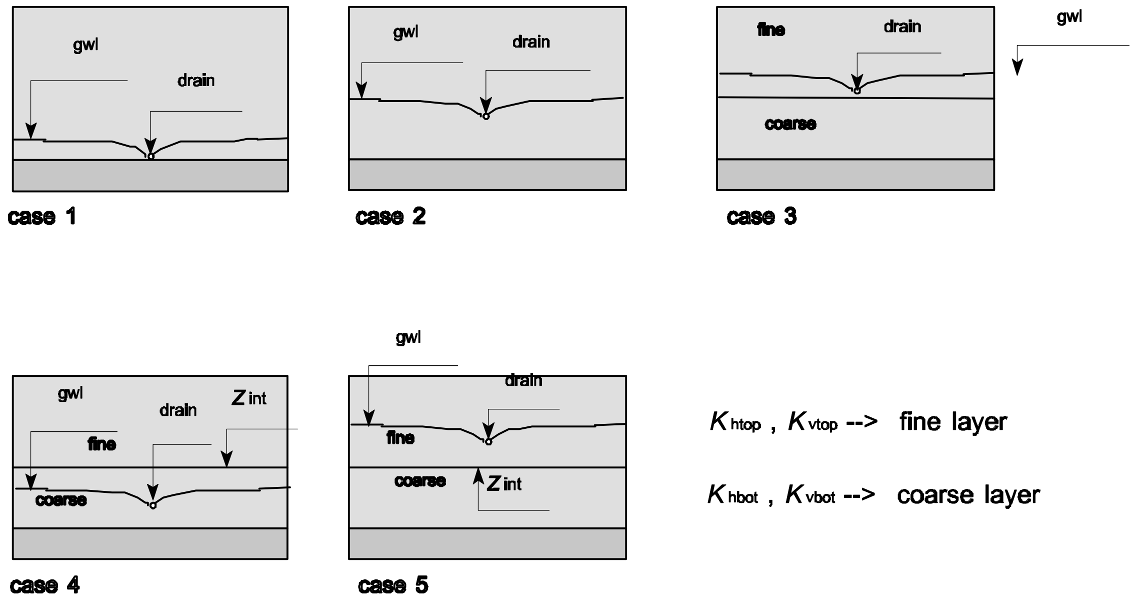


Fig. 5 Five field drainage situations considered in SWAP (after Ritzema, 1994). The hydraulic head f is defined positive upward with f = 0 at the soil surface.

Table 2: G_{dr} as obtained by the relaxation method (Ernst 1962).

K_{hbot}/K_{htop}	D_{bot}/D_{top}					
	1	2	4	8	16	32
1	2.0	3.0	5.0	9.0	15.0	30.0
2	2.4	3.2	4.6	6.2	8.0	10.0
3	2.6	3.3	4.5	5.5	6.8	8.0
5	2.8	3.5	4.4	4.8	5.6	6.2
10	3.2	3.6	4.2	4.5	4.8	5.0
20	3.6	3.7	4.0	4.2	4.4	4.6
50	3.8	4.0	4.0	4.0	4.2	4.6

D_{bot} is thickness of bottom layer; D_{top} is thickness of top layer. For more information see paragraph 8.4 in Van Dam et al (1997).

The drain characteristics, which need to be specified, are the same for all 5 different drainage situations and are rather self-explanatory. The value for the entry resistance [0..1000 d, R] can be obtained, analogous to the resistance value of an aquitard, by dividing the wet perimeter of the channel walls by the hydraulic conductivity. If the hydraulic conductivity does not differ substantially from the conductivity of the surrounding subsoil, the numerical value of the entry resistance will become relatively small.

4.13.4 Section 4: Drainage and infiltration resistance

A linear relationship between the average groundwater level and the drainage or infiltration flux is considered in this option. Up to five different drainage levels can be specified. For each level the user can specify whether drainage or infiltration or both are allowed. Both the drainage and infiltration resistance needs to be specified by the user. SWAP provides this option because it is conceivable that the infiltration and drainage resistance differ because of differences in groundwater table, local permeability, or preferential flow to the drain.

The drain spacing does not need to be specified if the user has not chosen to distribute the drainage flux vertically (file *.SWA, section 10). Specify the level of the drainage medium bottom. SWAP will determine the drainage base by taking the maximum of the drainage medium bottom and the surface water level. If a channel is considered, the water level in the channel as a function of time needs to be specified additionally.

```
**********************************************************************************
* Filename: Hupsel.DRB
* Contents: SWAP 2.0 - Basic lateral drainage
**********************************************************************************
*c Comment area:
*c
*c Case: Water and solute transport in the Hupsel area,
*c       a catchment in the eastern part of the Netherlands
*c
*c Example of the User's Guide: reference situation
*c
*c A set of input data to explore SWAP
**********************************************************************************


**********************************************************************************
* Section 1: Method
*
  DRAMET = 2 ! Switch, method of lateral drainage calculation:
*             1 = Use table of drainage flux - groundwater level relation
*             2 = Use drainage formula of Hooghoudt or Ernst
*             3 = Use drainage/infiltration resistance, multi-level if needed
**********************************************************************************

**********************************************************************************
* Section 2: Table of drainage flux - groundwater level relation
*
* In case drainage fluxes should be distributed vertically in the saturated
* zone (SWDIVD = 1 in *.SWA), specify the distance L between drainage canals:
  LM1 = 30.  ! Drain spacing, [1..1000 m, R]

* Specify drainage flux [cm/d, R] as function of groundwater level [cm, R,
* negative below soil surface]; start with highest groundwater level:
* GWL     Q      (maximum 25 records)
  -20.0   0.5
  -100.   0.1
* End of table
**********************************************************************************
```

File Hupsel.drb, example of a input file with data on basic drainage, section 1 - 2

```
**********************************************************************************
* Section 3: Drainage formula of Hooghoudt or Ernst
*
  IPOS = 2   ! Position of drain:
*              1 = On top of an impervious layer in a homogeneous profile
*              2 = Above an impervious layer in a homogeneous profile
*              3 = At the interface of a fine upper and a coarse lower soil layer
*              4 = In the lower, more coarse soil layer
*              5 = In the upper, more fine soil layer

* Of the next parameters, always specify BASEGW and KHTOP,
*                        KHBOT and ZINTF in case IPOS = 3,4 or 5,
*                        KVTOP and KVBOT in case IPOS = 4 or 5,
*                        GEOFAC in case IPOS = 5
  BASEGW = -200.    ! Level of impervious layer, [-1E4..0 cm, R, neg. below soil surf.]
  KHTOP  =  25.0    ! Horizontal hydraulic conductivity top    layer, [0..1000 cm/d, R]
  KHBOT  =  10.0    ! horizontal hydraulic conductivity bottom layer, [0..1000 cm/d, R]
  KVTOP  =   5.0    ! Vertical   hydraulic conductivity top    layer, [0..1000 cm/d, R]
  KVBOT  =  10.0    ! Vertical   hydraulic conductivity bottom layer, [0..1000 cm/d, R]
  GEOFAC =  4.8     ! Geometry factor of Ernst,  [0..100 -, R]
  ZINTF  = -150.    ! Level of interface of fine and coarse soil layer, [-1E4..0 cm, R]

* Always specify:
  LM2    = 11.      ! Drain spacing, [1..1000 m, R]
  WETPER =  30.0    ! Wet perimeter of the drain,  [0..1000 cm, R]
  ZBOTDR = -80.0    ! Level of drain bottom, [-1000..0 cm, R, neg. below soil surface]
  ENTRES =  20.0    ! Drain entry resistance, [0..1000 d, R]
**********************************************************************************


**********************************************************************************
* Section 4: Drainage and infiltration resistance
*
  NRLEVS = 2  ! Number of drainage levels, [1..5, I]
**********************************************************************************


**********************************************************************************
* Section 4a: Drainage to level 1
*
  DRARES1 = 100   ! Drainage resistance, [10..1E5 d, R]
  INFRES1 = 100   ! Infiltration resistance, [0..1E5 d, R]
  SWALLO1 =   1   ! Switch, for allowance drainage/infiltration:
*                   1 = Drainage and infiltration are both allowed
*                   2 = Drainage is not allowed
*                   3 = Infiltration is not allowed

* In case drainage fluxes should be distributed vertically in the saturated
* zone (SWDIVD = 1 in *.SWA), specify the distance L1 between drainage canals
  L1   = 20.      ! Drain spacing, [1..1000 m, R]

  ZBOTDR1 = -90.0 ! Level of drainage medium bottom, [-1000..0 cm, R]
  SWDTYP1 = 2     ! Type of drainage medium:
*                   1 = Drain tube
*                   2 = Open channel

* In case SWDTYP1 = 2, specify date [day month] and channel water level [cm, negative
* if below field surface], maximum 366 records:
* dd mm LEVEL1
  01 01  -90.0
  31 12  -90.0
* End of table
**********************************************************************************
```

File Hupsel.drb, example of a input file with data on basic drainage, section 3 – 4a

```
********************************************************************************
* Section 4b: Drainage to level 2
*
  DRARES2 = 100   ! Drainage resistance, [10..1E5 d, R]
  INFRES2 = 100   ! Infiltration resistance, [0..1E5 d, R]
  SWALLO2 =   1   ! Switch, for allowance drainage/infiltration:
*                   1 = Drainage and infiltration are both allowed
*                   2 = Drainage is not allowed
*                   3 = Infiltration is not allowed

* In case drainage fluxes should be distributed vertically in the saturated
* zone (SWDIVD = 1 in *.SWA), specify the distance L2 between drainage canals
  L2 = 20.        ! Drain spacing, [1..1000 m, R]

  ZBOTDR2 = -90.0 ! Level of drainage medium bottom, [-1000..0 cm, R]
  SWDTYP2 = 2     ! Type of drainage medium:
*                   1 = Drain tube
*                   2 = Open channel

* In case SWDTYP2 = 2, specify date [day month] and channel water level [cm, negative
* if below field surface], maximum 366 records:
* dd mm LEVEL2
  01 01  -90.0
  31 12  -90.0
* End of table
********************************************************************************


********************************************************************************
* Section 4c: Drainage to level 3
*
  DRARES3 = 100   ! Drainage resistance, [10..1E5 d, R]
  INFRES3 = 100   ! Infiltration resistance, [0..1E5 d, R]
  SWALLO3 =   1   ! Switch, for allowance drainage/infiltration:
*                   1 = Drainage and infiltration are both allowed
*                   2 = Drainage is not allowed
*                   3 = Infiltration is not allowed

* In case drainage fluxes should be distributed vertically in the saturated
* zone (SWDIVD = 1 in *.SWA), specify the distance L3 between drainage canals
  L3 = 20.        ! Drain spacing, [1..1000 m, R]

  ZBOTDR3 = -90.0 ! Level of drainage medium bottom, [-1000..0 cm, R]
  SWDTYP3 = 2     ! Type of drainage medium:
*                   1 = Drain tube
*                   2 = Open channel

* In case SWDTYP3 = 2, specify date [day month] and channel water level [cm, negative
* if below field surface], maximum 366 records:
* dd mm LEVEL3
  01 01  -90.0
  31 12  -90.0
* End of table
********************************************************************************
```

File Hupsel.drb, example of a input file with data on basic drainage, section 4b – 4c

```
*********************************************************************************
* Section 4d: Drainage to level 4
*
  DRARES4 = 100   ! Drainage resistance, [10..1E5 d, R]
  INFRES4 = 100   ! Infiltration resistance, [0..1E5 d, R]
  SWALLO4 =   1   ! Switch, for allowance drainage/infiltration:
*                  1 = Drainage and infiltration are both allowed
*                  2 = Drainage is not allowed
*                  3 = Infiltration is not allowed

* In case drainage fluxes should be distributed vertically in the saturated
* zone (SWDIVD = 1 in *.SWA), specify the distance L4 between drainage canals
  L4 = 20.        ! Drain spacing, [1..1000 m, R]

  ZBOTDR4 = -90.0 ! Level of drainage medium bottom, [-1000..0 cm, R]
  SWDTYP4 = 2     ! Type of drainage medium:
*                  1 = Drain tube
*                  2 = Open channel

* In case SWDTYP4 = 2, specify date [day month] and channel water level [cm, negative
* if below field surface], maximum 366 records:
* dd mm LEVEL4
  01 01  -90.0
  31 12  -90.0
* End of table
*********************************************************************************

*********************************************************************************
* Section 4e: Drainage to level 5
*
  DRARES5 = 100   ! Drainage resistance, [10..1E5 d, R]
  INFRES5 = 100   ! Infiltration resistance, [0..1E5 d, R]
  SWALLO5 =   1   ! Switch, for allowance drainage/infiltration:
*                  1 = Drainage and infiltration are both allowed
*                  2 = Drainage is not allowed
*                  3 = Infiltration is not allowed

* In case drainage fluxes should be distributed vertically in the saturated
* zone (SWDIVD = 1 in *.SWA), specify the distance L5 between drainage canals
  L5 = 20.        ! Drain spacing, [1..1000 m, R]

  ZBOTDR5 = -90.0 ! Level of drainage medium bottom, [-1000..0 cm, R]
  SWDTYP5 = 2     ! Type of drainage medium:
*                  1 = Drain tube
*                  2 = Open channel

* In case SWDTYP5 = 2, specify date [day month] and channel water level [cm, negative
* if below field surface], maximum 366 records:
* dd mm LEVEL5
  01 01  -90.0
  31 12  -90.0
* End of table

* End of file ********************************************************************
```

File Hupsel.drb, example of a input file with data on basic drainage, section 4d – 4e

4.14 Extended Drainage (*.dre)

4.14.1 General

This paragraph describes data requirements for applying the model to situations with extended drainage. The term `extended' means that the surface water levels are not prescribed independently, but are simulated as a result of the soil water balance and surface water management.
The groundwater-surface water system is schematised at the scale of a horizontal subregion. Only a single representative groundwater level is simulated, which is 'stretched' over a scale that in reality involves a variety of groundwater levels. Most of the theory has been described by Van Dam et al (1997, chapter 9), some additional remarks are given in this paragraph.
The input data for extended drainage are given in the input file with the extension *.DRE. This file is divided into 2 sections:

- section 1: drainage characteristics
- section 2: surface water system

Ahead of these sections, the user should specify the altitude of the control unit (= soil surface), with respect to a certain reference level (ALTCU). Water management levels are given with respect to the same reference. Of course the user may choose to define the soil as surface reference level by specifying zero for the altitude.

4.14.2 Section 1: drainage characteristics

Section 1 starts with the specification of the 'drainage resistance' for surface runoff, g_{sill}. A value of 0.1 d will be appropriate (in most cases). The maximum ponding depth (z_{sill}) is defined in the input file with soil water and profile data (file-extension *.SWA). The process of surface runoff is complicated and the user should be aware of the simplifications of reality applied to simulate surface runoff (Van Dam et al, 1997, chapter 9).
Next follows the specification of the number of drainage levels, *n*. This *excludes* the surface runoff. Section 1 continues with the specification of the 'orders' of drainage channels, in the input denoted as 'levels': at maximum 5 levels can be handled. In the module for extended drainage, level 1 involves the *deepest* channels in the considered subregion. This does not have to be the 'primary system'; it can also be the 'secondary' system (in that case the primary system is absent). Per level the user can specify whether it concerns 'channels' or 'drains'. So the user may specify that all of the levels are pipe drains. Apart from specifying its type, per drainage level the user must specify the following parameters:

– representative spacing between channels, L_{drain} (m!);
– bottom width of channel bed (only for channels), w_{drain} (cm!);
– groundwater level for maximum sub-irrigation rate, N_{avg}^{min} (cm).
– drainage resistance for situations with drainage, g_{drain} (d);
– drainage resistance for situations with infiltration , g_{inf} (d);
– entrance resistance for situations with drainage (only for channels), g_{entr} (d);
– entrance resistance for situations with infiltration (only for channels), g_{exit} (d);
– depth of channel bed /depth of drains, $z_{bed,i}$ (cm, negative!);
– side-slope of channels (only for channels, dz / dw_{drain}), $s_{drain\ (-)}$ (-);

In addition to the explanation given in chapter 9 of Van Dam et al (1997) it should be noted that for this 'quasi-subregional' approach the entrance resistance is included in the

expression for the total drainage resistance g_{tot} in the following manner:

$$g_{\text{tot}} = g_{\text{drain}} + \frac{L_{\text{drain}}}{u_{drain}} g_{\text{entr}} \qquad (5)$$

where u_{drain} is the wetted perimeter (cm), and g_{entr} is the entrance resistance (d) as given by Ernst (1956). In the case of channels, the wetted perimeter is computed, for each time step, from the surface water level N_{sur}, the channel bed level z_{bed}, the channel bed width w_{drain} and the channel side-slope s_{drain}. In the case of pipe drains however entrance/exit resistance is not calculated from the wetted perimeter and therefore should be included in the drainage/sub-irrigation resistance. If a parameter is not relevant (e.g. width of channel bed for drains), a dummy like "0." should be entered.
The content of Section 1 is given below for a situation with 2 levels of drainage.

```
********************************************************************************
* Filename: Hupsel.DRE
* Contents: SWAP 2.0 - extended drainage routine;
*                      example for interaction with surface water system
*******************************************************************************
*c Comment area:
*c
*c OMV calibration runs
*c
********************************************************************************

 ALTCU = 1200.0 ! ALTitude of the Control Unit relative to reference level
*                 AltCu = 0.0 means reference level coincides with
*                 surface level [-300000..300000 cm, R]

********************************************************************************
* Section 1: drainage characteristics
*
 RSRO   =  0.5 ! drainage Resistance of Surface RunOff [0.001..1.0 d, R]
*
 NRSRF  = 2    ! number of subsurface drainage levels [1..5, I]
*
*** Table with physical characteristics of each subsurface drainage level:
*
* LEVEL  ! drainage level number [1..NRSRF, I]
* SWDTYP ! type of drainage medium [open=0, closed=1]
* L      ! spacing between channels/drains [1..1000 m, R]
* ZBOTDR ! altitude of bottom of channel or drain [ALTCU-1000..ALTCU-0.01 cm,R]
* GWLINF ! groundw. level for max. infiltr. [-1000..0 cm rel. to soil surf., R]
* RDRAIN ! drainage resistance [1..100000 d, R]
* RINFI  ! infiltration resistance  [1..100000 d, R]
* Variables RENTRY, REXIT, WIDTHR and TALUDR must have realistic values when the
*          type of drainage medium is open (second column of this table:SWDTYP=0)
*          For closed pipe drains (SWDTYP=1) dummy values may be entered
* RENTRY ! entry resistance  [0..10 d, R]
* REXIT  ! exit resistance   [0..10 d, R]
* WIDTHR ! bottom width of channel [0..100 cm, R]
* TALUDR ! side-slope (dh/dw) of channel [0.01..5, R]
*
*LEV SWDTYP L      ZBOTDR GWLINF RDRAIN RINFI RENTRY REXIT  WIDTHR TALUDR
 1   0      250.0 1093.0 -350.0 150.0  4000.0  0.8    0.8  100.0  1.5
 2   0      200.0 1150.0 -300.0 150.0  1500.0  0.8    0.8  100.0  1.5
* End_of_table
********************************************************************************
```

File hupsel.dre, extended drainage, section1: characteristics of subsurface drainage systems

4.14.3 Section 2: surface water system

This part of the module (section 2) describes management and level of the surface water system. The various options may have a strong impact on the way the interactions are simulated. Any changes in the used option should therefore be followed by a complete 'go-through' of the input data file, in order to check the consistency. In order to help the user to do this, the sections of the input file have been indexed and a flow chart is given in figure 6.

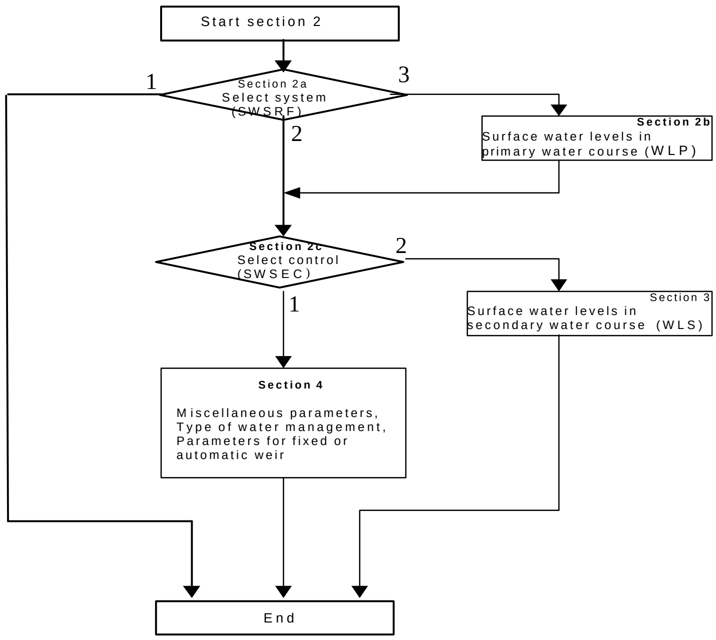


*Fig 6 low chart for input data of surface water system in input file *.dre*

Section 2 contains the specification of the surface water system.
This section starts with a switch (section 2a, variable SWSRF) for three modes to simulate the surface water system:

1. no surface water system is simulated;
2. surface water system is simulated with no separate primary water course;
3. surface water system is simulated with a primary water course (level 1) separate from the control unit

If the first option (SWSRF=1) has been chosen, the user may skip the rest of this input file.
For the second or third option (SWSRF=2 or 3) the user has also to specify (section 2c, variable SWSEC) how the surface water level in the control unit is determined:

1. the surface water level is simulated;
2. the surface water level is obtained from input data.

If the third option (SWSRF=3) has been chosen, the user should also specify (section 2b) the time variation of the surface water level in the primary water course. The specification is done in terms of data pairs (time, water level). For obtaining levels at intermediate dates, the program performs a linear interpolation.

If the option is chosen to obtain surface water levels from input data (SWSEC=2), the surface water level of the secondary watercourse has to be specified in the form of data pairs (section 3).

If the option is chosen to simulate surface water levels (SWSEC=1), the user has to specify how the surface water system in the control unit functions and how it is managed (section 4).

Section 4 starts with some miscellaneous parameters (section 4a):
- the initial surface water level in the control unit;
- the criterium for detecting oscillation of the surface water level;
- the number of water management periods.

Section 4b: for each management period the user should specify
- the index of the period
- the date that it ends
- the type of watermanagent (1- fixed weir crest; 2- automatic weir)
- the water supply capacity
- the allowed dip of the surface water level, before initiating the supply

Dependent on the discharge relationship for the weir, the user has to specify:
- either Section 4c (SWQHR=1, exponential relation)
- or Section 4d (SWQHR=2, relation given as table)

Section 4c: for each water management period with a fixed weir crest using weir characteristics, the user should specify:
- Size of the control unit (catchment) (ha);
- A table with weir characteristics for each management period:
  - Index for management period (-);
  - Elevation (H) of the weir crest (cm);
  - Weir coefficient α_{input} ($m^{3-\beta}$ s^{-1});
  - Weir coefficient β (-)

In Van Dam et al (1997) it was indicated that the head-discharge relationship is described with a simple equation (eq. 9.10). In that equation units conform to the rest of the model code, i.e. unit of length in cm and unit of time in d and the discharge is computed per unit of area (cm^3 cm^{-2} d^{-1} or
cm d^{-1}). However, in hydraulic literature (e.g. Working Group on Hydraulic Structures, 1976) head-discharge relationships are given in SI-units, i.e. m for length and s for time and the discharge is computed as a volume rate (m^3 s^{-1}). To facilitate the input for the user we conformed to hydraulic literature. This implies that the user has to specify the weir characteristics that define a relationship of the following form:

$$Q = a_{input} H^{b} \qquad (6)$$

where Q is the discharge (m^3 s^{-1}), H is the head above the crest (m) and a_{input} is a weir coefficient ($m^{3-\beta}$ s^{-1}), b is a weir exponent (-).
The only preparatory work that the user has to do is to compute the value of a_{input} from the various coefficients preceding the upstream head above the crest. For instance, for a broad-crested rectangular weir, a_{input} is (approximately) given by:

$$a_{input} = 1.7b \qquad (7)$$

where 1,7 is the discharge coefficient of the weir (based on SI-units), b is the width of the weir (m).

To correct for units, the model carries out the following conversion:

$$a_{weir} = \frac{8.64 * 100^{1-b}}{A_{cu}} a_{input} \qquad (8)$$

where A_{cu} is the size of the control unit (ha)
The model requires input of the size of the control unit (A_{cu}), which in simple cases will be identical to the size of the simulation unit.

Section 4d: For each water management period with a fixed weir crest using weir data the user should specify a table.

Section 4e: For each water management period with an automatic weir the user should specify:

- index of the management period
- the maximum allowed drop rate of the water level setting
- the depth (HDEPTH) in the soil profile for the pressure head criterium (HCRIT)

Within each management period, the water level of a secondary watercourse is defined by certain criteria that are defined in a table. This table should be given for each management period:

- the index of the management period;
- the phase *i* of the scheme
- the water level setting of the automatic weir in phase *i*, $j_{sur,tar}$
- the groundwater level criterium for allowing a weir setting, $j_{m,max}$
- the pressure head criterium for allowing a weir setting, $h_{\mathrm{p,max}}$
- the unsaturated volume criterium for allowing a weir setting, $V_{uns,min}$.

```
********************************************************************************
* Section 2a: Specification and control of surface water system
*
 SWSRF = 2 ! option for interaction with surface water system [1..3, I]
*            1 = no interaction with surface water system
*            2 = surf. water system is simulated with no separate primary system
*            3 = surf. water system is simulated with separate primary system
********************************************************************************
*
********************************************************************************
* Section 2b: Surface water level of primary system
*
* Only if SWSRF = 3 then the following table must be entered
* Table with Water Levels in the Primary system [max. = 52]:
* no levels above soil surface for primary system
*
* DATE : dd = daynumber [1..31, I]
*        mm = monthnumber [1..12, I]
* WLP  : water level in primary water course [ALTCU-1000..ALTCU-0.01 cm,R]
*
*DATE      WLP
*dd mm      cm
*End_of_table
********************************************************************************
*
********************************************************************************
* Section 2c: Surface water level of secondary system
*
* If SWSRF =  2 or 3  then the variable SWSEC must be entered
*
 SWSEC = 2 ! option for surface water level of secondary system [1..2, I]
*            1 = surface water level is input
*            2 = surface water level is simulated
********************************************************************************
```

File hupsel.dre, extended drainage, section 2a,2b,2c: surface water system, levels of primary and secondary water course

```
********************************************************************************
* Section 3: surface water level in secondary water course is input
*
* Table with Water Levels in the Secondary system [max. = 52]:
*
* DATE : dd = daynumber [1..31, I]
*        mm = monthnumber [1..12, I]
* WLS :  water level in secondary water course [ALTCU-1000..ALTCU+100 cm,R]
*
*DATE     WLS
*dd mm     cm
*End_of_table
********************************************************************************
```

File hupsel.dre, extended drainage, section 3: surface water level in secondary water course

```
********************************************************************************
* Section 4: surface water level is simulated
*
********************************************************************************
* Section 4a: Miscellaneous parameters
*
 WLACT  = 1123.0 ! initial surface water level [ALTCU-1000..ALTCU cm,R]
 OSSWLM =   2.5  ! criterium for warning about oscillation [0..10 cm, R]
********************************************************************************
*
********************************************************************************
* Section 4b: management of surface water levels
*
 NMPER  =  4    ! number of management periods [1..10, I]
*
* For each management period specify:
* IMPER  index of management period [1..NMPER, I]
* IMPEND date that period ends:
*        dd = daynumber [1..31, I]
*        mm = monthnumber [1..12,I]
* SWMAN  type of water management [1..2, I]
*        1 = fixed weir crest
*        2 = automatic weir
* WSCAP  surface water supply capacity [0..100 cm/d, R]
* WLDIP  allowed dip of surf. water level, before starting supply [0..100 cm, R]
* INTWL  length of water-level adjustment period (SWMAN=2 only) [1..31 d, R]
*
*IMPER IMPEND SWMAN WSCAP   WLDIP   INTWL
*       dd mm
  1     31 01   1    0.00     0.0     1
  2     01 04   2    0.00     5.0     1
  3     01 11   2    0.00     5.0     1
  4     31 12   1    0.00     0.0     1
*End_of_table
*
 SWQHR  = 1 ! option for type of discharge relationship [1..2, I]
*             1 = exponential relationship
*             2 = table
********************************************************************************
```

File hupsel.dre, extended drainage, section 4 (surface water level is simulated): miscellaneous and management parameters

```
********************************************************************************
* Section 4c: exponential discharge relation (weir characteristics)
*
* If SWQHR=1 and for ALL periods specify:
*
 SOFCU = 100.0  ! Size of the control unit [0.1..100000.0 ha, R]
*
* IMPER  index of management period [1..NMPER, I]
* HBWEIR weir crest; levels above soil surface are allowed, but simulated
*        surface water levels should remain below 100 cm above soil surface;
*        the crest must be higher than the deepest channel bottom of the
*        secondary system (ZBOTDR(1 or 2),  [ALTCU-ZBOTDR..ALTCU+100 cm,R].
*        If SWMAN = 2: HBWEIR represents the lowest possible weir position.
* ALPHAW alpha-coefficient of discharge formula [0.1..50.0, R]
* BETAW  beta-coefficient of discharge formula [0.5..3.0, R]
*
*IMPER  HBWEIR  ALPHAW  BETAW
  1    1114.0    3.0    1.4765
  2    1110.0    3.0    1.4765
  3    1110.0    3.0    1.4765
  4    1114.0    3.0    1.4765
*End_of_table
********************************************************************************
*
********************************************************************************
* Section 4d: table discharge relation
*
 LABEL4d = 1 ! Do not modify
*
* If SWQHR=2 and for ALL periods specify:
*
* IMPER  index of management period [1..NMPER, I]
* ITAB   index per management period [1..10, I]
* HTAB   surface water level [ALTCU-1000..ALTCU+100 cm, R]
*        (first value for each period = ALTCU + 100 cm)
* QTAB   discharge [0..500 cm/d, R]
*        (should go down to a value of zero at a level that is higher than
*        the deepest channel bottom of secondary surface water system)
*
*IMPER ITAB  HTAB    QTAB
*End_of_table
********************************************************************************
```

File hupsel.dre, extended drainage, section 4c and section 4d (surface water level is simulated): weir characteristics as exponential function (4c) or as table (4d)

```
********************************************************************************
* Section 4e: automatic weir control
*
 LABEL4e = 1 ! Do not modify
*
* For the periods when SWMAN=2 specify next two tables:
*
*** Table #1
*
*
* IMPER  index of management period [1..NMPER, I]
* DROPR  maximum drop rate of surface water level [0..100 cm/d, positive, R]
*        if the value is set to zero, the parameter does not play
*        any role at all
* HDEPTH depth in soil profile for comparing with HCRIT
*        [-100..0 cm below soil surface, R]
*
*IMPER DROPR   HDEPTH
  2    0.0     -15.0
  3    0.0     -15.0
*End_of_table
*
*** Table #2
*
* IMPER   index of management period [1..NMPER, I]
* IPHASE  index per management period [1..10, I]
* WLSMAN  surface water level of phase IPHASE [ALTCU-500.0..ALTCU cm,R]
* GWLCRIT groundwater level of phase IPHASE,  max. value
*         [-500..0 cm  below soil surface, R]
* HCRIT   critical pressure head, max. value, (at HDEPTH, see above)
*         for allowing surface water level [-1000..0 cm, neg., R]
* VCRIT   critical unsaturated volume (min. value) for all
*         surface water level [0..20 cm, R]
*
*   Notes: 1) The zero's for the criteria on the first record are in fact
*             dummy's, because under all circumstances the scheme will set
*             the surface water level at least to wlsman(imper,1)
*           2) The lowest level of the scheme must still be above the
*             deepest channel bottom of the secondary surface water system
*
*IMPER IPHASE WLSMAN GWLCRIT   HCRIT   VCRIT
  2     1    1114.0     0.0      0.0     0.0
  2     2    1124.0   -80.0      0.0     0.0
  2     3    1124.0   -90.0      0.0     0.0
  2     4    1154.0  -100.0      0.0     0.0
  3     1    1114.0     0.0      0.0     0.0
  3     2    1124.0   -80.0      0.0     0.0
  3     3    1124.0   -90.0      0.0     0.0
  3     4    1154.0  -100.0      0.0     0.0
*End_of_table
********************************************************************************
```

File hupsel.dre: extended drainage, section4e: surface water level is simulated with automatic weir control

4.15 Bottom boundary conditions (*.bbc)

The bottom boundary condition in SWAP is considered separate of the drainage or infiltration flux, which is specified in the file *.DRB (Par. 4.13) for basic drainage or *.DRE (Par. 4.14) for drainage extended to surface water. The drainage or infiltration flux applies to local groundwater flow, which is directly affected by local surface water management. The drainage/infiltration flux is considered to leave/enter the soil profile horizontally. The bottom boundary conditions, which always should be specified, should include the influence of groundwater flow on larger scale, which is not affected by local surface water management. Instead of defining the local drainage fluxes separately, the user may choose to include the local drainage fluxes in the bottom boundary condition. In that case the effect of changes in local surface water management on the field scale water balance cannot be simulated.

SWAP allows eight different bottom boundary conditions:
1) Groundwater level is given
2) Regional bottom flux is given
3) Flux from deep aquifer is calculated
4) Upward flux calculated as a function of groundwater
5) Pressure head of bottom compartment is given
6) Zero flux at the bottom of the profile
7) Free drainage at the bottom of the profile
8) Lysimeter with free drainage

Ad 1) Groundwater level is given
Up to 366 records can be entered to describe the ground water level as a function of time. Similar to other data that are given as function of time, SWAP will interpolate between data pairs. Note that if in file *.SWA, section 11, an initial soil water profile in equilibrium with the groundwater level has been specified, the defined ground water level in this section determines the initial soil water profile.

Ad 2) Regional bottom flux is given
The user can either use a table to specify the regional bottom flux, or use a sine function to generate a regional bottom flux. If a sinusoidal bottom flux is defined, the user should provide mean [-10..10 cm/d, R], amplitude [-10..10 cm/d, R] and the day number [1..366, I] at which the maximum of the sine wave occurs. Positive values for the function are an upward flux, while negative values are a downward flux.

Ad 3) Flux from a deep aquifer is calculated.
In this case q_{bot} is calculated from an aquifer below an aquitard. Since the shape of the groundwater above the aquitard is important in calculating the average groundwater level, the user should specify a shape factor of the phreatic surface and the mean drainage base (depth) (see Fig. 2.6 and Par. 2.4.3 in Van Dam et al., 1997). Possible values for the shape factor are 0.66 (parabolic), 0.64 (sinusoidal), 0.79 (elliptic) and 1.00 (no drains, flat). The bottom flux is calculated using the hydraulic head difference between the phreatic groundwater and the groundwater in the semi-confined aquifer and the resistance of the semi-confining layer.

The user should also specify the parameters defining the sine wave in the aquifer (similar to condition 2). The user should enter subsequently:
- the amplitude or maximum deviation of the sine wave;
- the daynumber at which the maximum occurs;

- the period of the sine wave.

Ad 4) Upward flux calculated as a function of groundwater

The exponential relationship was developed for deep sandy areas in the Netherlands, so care should be taken when this condition is used in other areas. The user should specify the coefficients in the exponential relationship. Van Dam et al (1997) refer to Massop and De Wit (1994) and Ernst and Feddes (1979) for examples of these relationships.

Ad 5) Pressure head of the bottom compartment is given

In general this is called a Dirichlet condition. The user can specify up to 366 pressure heads [-1.E10..1.E5 cm, R] in the table.

Ad 6) Zero flux at the bottom of the profile

This condition can be used if an impermeable layer exists at the bottom of the profile.

Ad 7) Free drainage at the bottom of the soil profile

This condition applies to soil profiles with deep groundwater levels, for which unit gradient of hydraulic head can be assumed at the bottom boundary. Mind that the accuracy of the simulated water contents depends to a large extent on the accuracy of the specified unsaturated hydraulic conductivity function.

Ad 8) Lysimeter with free drainage

This option can be used if free outflow at a soil-air interface is to be simulated. Drainage will only occur if the pressure head in the bottom compartment increases until above zero. If the pressure head is negative, a no flux boundary applies.

```
*********************************************************************************
* Filename: Hupsel.BBC
* Contents: SWAP 2.0 - Bottom Boundary Condition
*********************************************************************************
*c Comment area:
*c
*c
*********************************************************************************

* Choose one of 8 options:

  SWOPT1 = 0     ! Switch, use groundwater level, [Y=1, N=0]
*
* If SWOPT1 = 1, specify date [day month] and groundwater level [cm, neg. below
*                soil surface], maximum 366 records:
* d1 m1  GWlevel
   1  1  -95.0
  31 12 -110.0
* End of table
*********************************************************************************

  SWOPT2 = 0     ! Switch, use regional bottom flux [Y=1, N=0]
*
* If SWOPT2 = 1, specify whether a sine or a table are used to prescribe the flux:
  SWC2   = 2     ! Sine function = 1,  table = 2

* In case of sine function, specify:
  C2AVE =  0.1   ! Average value of bottom flux, [-10..10 cm/d, R, + = upwards]
  C2AMP =  0.05  ! Amplitude of bottom flux sine function, [-10..10 cm/d, R]
  C2MAX =  91    ! Daynumber with maximum bottom flux, [1..366 d, I]

* In case of table, specify date (day month) and bottom flux [cm/d, + = upwards]:
* d2 m2  Qbot  (maximum 366 records)
   1  1  0.10
   5  6  0.20
  31 12  0.10
* End of table
*********************************************************************************

  SWOPT3 = 0     ! Switch, calculate bottom flux from deep aquifer, [Y=1, N=0]
*
* If SWOPT3 = 1, specify:
  SHAPE  = 0.79   ! Shape factor to derive average groundwater level, [0..1 -, R]
  HDRAIN = -110.0 ! mean drainage base used to correct groundw. level [-1.e4..0 cm, R]
  RIMLAY = 500    ! Vertical resistance of aquitard, [0..10000 d, R]
  AQAVE  = -140.0 ! Average hydraulic head in aquifer [-1000..1000 cm, R]
  AQAMP  = 20.0   ! Amplitude hydraulic head sinus wave, [0..1000 cm, R]
  AQTAMX = 120    ! First daynumber (Jan 1 = 1) with top hydraulic head, [1..366 d, I]
  AQPER  = 365    ! Period hydraulic head sinus wave, [1..366 d, I]
*********************************************************************************

  SWOPT4 = 0     ! Switch, calc. bottom flux as function of groundw. level, [Y=1, N=0]
*
* If SWOPT4 = 1, specify of q = A exp (Bh) relation:
  COFQHA =  -    ! Coefficient A, [-100..100 cm/d, R]
  COFQHB =  -    ! Coefficient B  [-1..1 /cm, R]
*********************************************************************************

  SWOPT5 = 0     ! Switch, use pressure head of bottom compartment, [Y=1, N=0]
*
* If SWOPT5 = 1, specify date [day month] and bottom compartment pressure
*                head [cm, negative if unsaturated], maximum 366 records:
* d5 m5  GWlevel
   1  1   50.0
  31 12   20.0
* End of table
*********************************************************************************

  SWOPT6 = 1     ! Switch, bottom flux equals zero, [Y=1, N=0]
  SWOPT7 = 0     ! Switch, free drainage of soil profile, [Y=1, N=0]
  SWOPT8 = 0     ! Switch, free outflow at soil-air interface, [Y=1, N=0]

* End of file ********************************************************************
```

File hupsel.bbc: bottom boundary conditions

4.16 Heat flow (*.hea)

This file needs to be provided if the user has indicated simulation of heat transport in the SWAP.KEY file, section 5. Heat transport in SWAP can be simulated either analytically or numerically.

4.16.1 Section 2: Analytical method

The analytical method assumes soil thermal diffusivity and soil heat capacity to be constant. In this case the heat flow equation can easily be solved assuming a sinusoidal variation of the temperature through the year. The user should specify the mean, amplitude and the daynumber with the maximum air temperature. Additionally the user should specify the damping depth, which is a function of the heat diffusivity (see equation 4.8 in Par. 4.2 of Van Dam et al, 1997). No soil thermal properties need to be specified under this option.

4.16.2 Section 3: Numerical method

The initial soil temperatures should be entered. SWAP uses the average daily temperature calculated form the meteo file `station.yyy' as a top boundary condition and assumes a zero flux boundary at the bottom compartment.

In addition, the soil thermal properties should be entered. SWAP uses the fraction of clay, sand, and organic matter to calculate the soil thermal properties. SWAP assumes that the solid fraction (fraction of the soil that is not water or air) is build up out of clay, sand and organic matter. By supplying the fractions clay and sand, the organic matter fraction is known. The soil thermal properties are strongly affected by the actual water content.

```
**********************************************************************************
* Filename: Hupsel.HEA
* Contents: SWAP 2.0 - Heat flow data
**********************************************************************************
*c Comment area:
*c
*c Case: Water and solute transport in the Hupsel area,
*c       a catchment in the eastern part of the Netherlands
*c
*c Example of the User's Guide: reference situation
*c
*c A set of input data to explore SWAP
**********************************************************************************

**********************************************************************************
* Section 1: Method
*
  SWSHF = 2     ! Switch, method:
*                 1 = Use analytical method
*                 2 = Use numerical method
**********************************************************************************


**********************************************************************************
* Section 2: Analytical method
*
  TAMPLI = 10.0 ! Amplitude of annual temperature wave at soil surface, [0..50 C, R]
  TMEAN  = 15.0 ! Mean annual temperature at soil surface, [5..30 C, R]
  DDAMP  = 50.0 ! Damping depth of temperature wave in soil, [0..200 cm, R]
  TIMREF = 90.0 ! Day number (Jan 1 = 1) at top sine temperature wave [1..366 d, I]
**********************************************************************************


**********************************************************************************
* Section 3: Numerical method
*
* List initial temperature of each compartment (max 40), [-10..40 C, R]
  TEMPI =
    6.0    6.0    6.0    6.0    6.0    6.0    6.0    6.0    6.0    6.0
    6.0    6.0    6.0    6.0    6.0    6.0    6.0    6.0    6.0    6.0
    6.0    6.0    6.0    6.0    6.0    6.0    6.0    6.0    6.0    6.0
    6.0    6.0    6.0    6.0    6.0    6.0


* End of file ********************************************************************
```

File hupsel.hea: heat flow data

4.17 Solute transport (*.slt)

Input data for this option only need to be specified if the user has indicated simulation of solute transport in SWAP.KEY, section 5. Solute transport is simulated deterministically in SWAP by describing the physical processes. The basic solute transport, as used for salt transport, employs the convection-dispersion equation. Options are provided for the user to include adsorption and decomposition of reactive solutes. SWAP is focussed on the transport of salts, pesticides and other solutes that can be described with relatively simple kinetics. If detailed pesticide transport should be simulated, SWAP can be used in combination with PESTLA (Berg and Boesten, 1998). If detailed nitrate transport should be simulated, SWAP can be used in combination with ANIMO (Groenendijk and Kroes, 1998).

4.17.1 Section 1: Top boundary and initial condition

This section starts with the solute concentration in the precipitation. In order to establish the initial conditions for the solute transport, the user should specify the solute concentrations in mg/cm^3 of each compartment.

4.17.2 Section 2: Diffusion, dispersion, and solute uptake by roots

The user should specify:

- the dispersion length (D/v), for which Jury et al. (1991) indicated a value between 0.5 and 2 cm in case of packed laboratory columns and a value between 5 and 20 cm for field conditions;
- the molecular diffusion coefficient, in the order of 0.012 cm^2/day, which is generally much smaller than the dispersion coefficient and in most field conditions can be neglected.
- the solute uptake factor K_r for the roots; if $K_r > 1$, solutes are taken up at a higher rate than would follow from soil water uptake rate by roots times the solute concentration.

4.17.3 Section 3: Adsorption

If the user wants to consider solute adsorption, implying delay of solute breakthrough because part of the solute is adsorbed to the soil particles, the user should supply the following parameters:

- Freundlich coefficient; in case of linear adsorption this parameter is equal to the slope of the adsorption-desorption curve;
- Freundlich exponent; this parameter determines whether the adsorption is non-linear. In case of linear adsorption the user should specify a value of 1;
- reference value of the solute concentration, which is used to make the Freundlich exponent dimensionless.

4.17.4 Section 4: Decomposition

Solute decomposition is calculated from a potential solute decomposition rate, which applies to soil from the plow layer at 20 °C and at a suction h = -100 cm. The potential decomposition rate is reduced under the influence of temperature, soil water content and depth in the soil profile. Details are provided in paragraph 3.3 of Van Dam et al (1997).

The user should specify:

- potential decomposition rate [/d];
- temperature parameter γ_T , used to calculate the reduction factor due to temperature (Van Dam et al., 1997, page 43);
- minimum water content for potential decomposition [-];
- exponent of the relation proposed by Walker (1974) to describe reduction of decomposition due to dryness [-];
- of each layer a decomposition reduction factor due to depth [-], which can only be derived from field experiments.

4.17.5 Section 5: Transfer between mobile and immobile water volumes

If preferential flow due to unstable wetting fronts is modelled, SWAP uses the two domain mobile-immobile model. Since the fraction of mobile water has already been specified in file *.SWA, section 8, only the solute exchange rate between the mobile and immobile parts should be specified here [/d].

4.17.6 Section 6: Solute residence in the saturated zone

In this section the user may specify parameters to calculate the solute breakthrough to surface water. In the saturated zone only linear adsorption and first order decomposition can be considered. In case no breakthrough curve should be simulated, the user only needs to enter the solute concentration in the aquifer, which will be used as a lower boundary condition. In case a breakthrough to surface water should be modelled, the following parameters should be specified:

- thickness of the aquifer for solute breakthrough [cm];
- porosity of the aquifer [-];
- linear adsorption coefficient for the aquifer [cm^3/mg]; specify 0 if no adsorption takes place;
- decomposition rate in the aquifer [/d];
- initial solute concentration in the aquifer [mg/cm^3].

```
**********************************************************************************
* Filename: Hupsel.SLT
* Contents: SWAP 2.0 - Solute data
**********************************************************************************
*c Comment area:
*c
*c Case: Water and solute transport in the Hupsel area,
*c       a catchment in the eastern part of the Netherlands
*c
*c Example of the User's Guide: reference situation
*c
*c A set of input data to explore SWAP
**********************************************************************************


**********************************************************************************
* Section 1: Top boundary and initial condition
*
  CPRE = 0.0    ! Solute concentration in precipitation, [0..100 mg/cm3, R]

* List initial solute concentration of each comp. (max 40), [0..1000 mg/cm3, R]:
  CMLI =
    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
    0.0    0.0    0.0    0.0    0.0    0.0
**********************************************************************************


**********************************************************************************
* Section 2: Diffusion, dispersion, and solute uptake by roots
*
  DDIF = 0.0    ! Molecular diffusion coefficient, [0..10 cm2/day, R]
  LDIS = 5.0    ! Dispersion length, [0..100 cm, R]
  TSCF = 0.0    ! Relative uptake of solutes by roots, [0..10 -, R]
**********************************************************************************
```

File hupsel.slt: solute data, section 1 – 2

```
**********************************************************************************
* Section 3: Adsorption
*
  SWSP = 0    ! Switch, consider solute adsorption [Y=1, N=0]

* If SWSP = 1,  specify:
  KF    = 1.0   ! Freundlich coefficient, [0..100 cm3/mg, R]
  FREXP = 0.9   ! Freundlich exponent, [0..10 -, R]
  CREF  = 1.0   ! Reference solute concentration for adsorption, [0..1000 mg/cm3, R]
**********************************************************************************

**********************************************************************************
* Section 4: Decomposition
*
  SWDC = 0    ! Switch, consider solute decomposition [Y=1, N=0]

* If SWDC = 1,  specify:
  DECPOT = 0.0  ! Potential decomposition rate, [0..10 /d, R]
  GAMPAR = 0.0  ! Factor reduction decomposition due to temperature, [0..0.5 /C, R]
  RTHETA = 0.3  ! Minimum water content for pot. decomposition, [0..0.4 cm3/cm3, R]
  BEXP   = 0.7  ! Exponent in reduction decomposition due to dryness, [0..2 -, R]

* List the reduction of pot. decomposition for each soil layer (max 5), [0..1 -, R]:
  FDEPTH =   1.0     0.5
**********************************************************************************


**********************************************************************************
* Section 5: Transfer between mobile and immobile water volumes (if present)
*
  SWPREF = 0     ! Switch, consider mobile-immobile water volumes [Y=1, N=0]

* If SWPREF = 1, specify:
  KMOBIL = 0.0   ! Solute transfer coef. between mobile-immobile parts, [0..100 /d, R]
**********************************************************************************


**********************************************************************************
* Section 6: Solute residence in the saturated zone
*
  SWBR = 0       ! Switch, consider mixed reservoir of saturated zone [Y=1, N=0]

* If SWBR = 0,  specify:
  CDRAIN  = 0.0   ! solute concentration in groundwater, [0..100 mg/cm3, R]

* If SWBR = 1,   specify:
  HAQUIF = 110.0 ! Thickness saturated part of aquifer, [0..10000 cm, R]
  POROS  = 0.4   ! Porosity of aquifer, [0..0.6, R]
  KFSAT  = 0.0   ! Linear adsorption coefficient in aquifer, [0..100 cm3/mg, R]
  DECSAT = 0.0   ! Decomposition rate in aquifer, [0..10 /d, R]
  CDRANI  = 0.0   ! Initial solute concentration in groundwater, [0..100 mg/cm3, R]

* End of file ********************************************************************
```

File hupsel.slt: solute data, section 3 – 6

5 Program execution and output

5.1 Program execution

The general input file Swap.key must be present at the same directory as the executable SWAP.
All other input files should exist on the directory, which has been specified in the file Swap.key (par. 4.2.1). The output files will be written to this directory.

A simulation is executed by entering the name of the executable SWAP (e.g. sw207_32.exe) directly from the command line. Indirectly a simulation can be executed by entering the name of a batch-file. Along with the program a simple batch-file is supplied in the directory of the examples.

The program is protected against extreme incorrect values of input parameters. A range check is performed on the upper and lower boundary values of most input parameters. Error messages will be written to the screen or to a file called Swap.log, which will be generated at the same directory from where the program is executed. A consistency check of all options and corresponding parameter values however is impossible. It is therefore required that users have basic knowledge of the modelled processes.

5.2 Program output

The program may generate various ASCII output files (see figure 3) which can be switch on/of by means of variables given at the end of the general input file Swap.key.

The sub-model for Soil may produce the following output files:
– Water balance with cumulative data (*.wba)
– Water balance with data for time increments (*.inc)
– Water balance with data cumulative over time and vertical space (*.bal)
– Solute balance (*.sba)
– Soil temperature (*.tep)
– Soil moisture-, solute- and temperature- profiles (*.vap)
– Interaction with surface water (Extended Drainage) (*.drf, *.swb, *.man)

The sub-model for irrigation may generate simulated irrigation gifts (*.sc1, *.sc2, *.sc3).

The sub-model for Crop will generate files with crop growth status (*.cr1, *.cr2, *.cr3).

Formatted and unformatted (binary) export files for can be generated with data that cover the entire simulation period (*.afo, *.aun, *.ate, *.air). These output files can be directly used as input for pesticide and nutrient models like PESTLA (Berg and Boesten, 1998) and ANIMO (Kroes and Roelsma, 1998). A description of the files *.afo and *.aun is given in annex D.

Three additional files will be generated automatically:
– a file with error messages (swap207.log)
– a file with final pressure heads of all compartments (Hfinal.dat) an empty file which is only relevant when the Graphical User Interface is applied (Suc.cex)

6 Examples

The examples in this chapter serve as exercises and intend to make you familiar with basic features of the agrohydrological model SWAP and the way input and output are arranged. You will simulate a field case for water flow, solute transport and crop growth in the Hupsel catchment. Subsequently the following items are considered by changing the input for a reference situation and analysing the simulation results:

– meteorological year
– irrigation
– crop type
– evapotranspiration of partly covered soil
– soil texture
– hysteresis of retention function
– scaling of soil hydraulic functions
– root density distribution
– bromide breakthrough to surface water
– drainage design

After carrying out the exercises the reader should be able to use SWAP for his/her own agrohydrologic research.

In paragraph 6.1 the reference situation is described and in paragraph 6.2 exercises are discussed.

Additional input files are supplied in the directory \DATA\ :

- Daily weather data of Wageningen meteo station for a period of 40 years (1954-1993);
- Data files for detailed crop growth at West-European conditions of winter wheat, grain maize, spring barley, rice, sugar beet, potato, field bean, soy bean, winter oil seed, rape and sunflower, as adapted from Prins et al., (1993);
- Soil hydraulic functions of the Staring Series (Wösten et al., 1994).

6.1 The reference situation

The input files that are required to carry out the exercises are supplied with the program. The input data files for the reference situation are located in the directory \REFERENC\. These data should not be changed and serve as initial condition for the exercises discussed in par. 6.2.

6.1.1 Introduction

In the reference run a simulation is carried out for water and solute transport in the variably saturated zone at an experimental field in the Hupsel catchment in the East of the Netherlands. Measured meteorological data of the Wageningen weather station are used to calculate evapotranspiration according to the Penman-Monteith equation (Van Dam et al, 1997, par. 6.2). The weather data belong to the year 1980, which is more or less an average meteorological year for the considered region. Daily rainfall data are used as surface runoff is not expected. The climatic conditions are such that no irrigation is needed. The field is cultivated with maize, which emerges 1 May, and is harvested 15 October. Maize growth is not simulated, but instead the simple crop routine is selected to prescribe

leaf area index, soil cover, crop height and rooting depth as function of development stage (see Table 3). A triangular root density distribution is assumed. The soil profile contains loamy sand, both in the top and in the subsoil. The soil hydraulic data of the two soil layers are derived from Wösten et al. (1994) (Van Dam et al, 1997, Annex A). In the reference case no hysteresis or scaling of the soil hydraulic functions is considered. Also preferential flow due to immobile soil volumes or shrinkage cracks is not taken into account. Drains are located at 0.80 m depth and are spaced 11 m apart. An impermeable boulder clay layer occurs at 2.0 m depth. For calculation of solute breakthrough curve to the surface water, the mean thickness of the phreatic aquifer is estimated at 1.10 m.
Figure 7 gives an overview of the considered case.

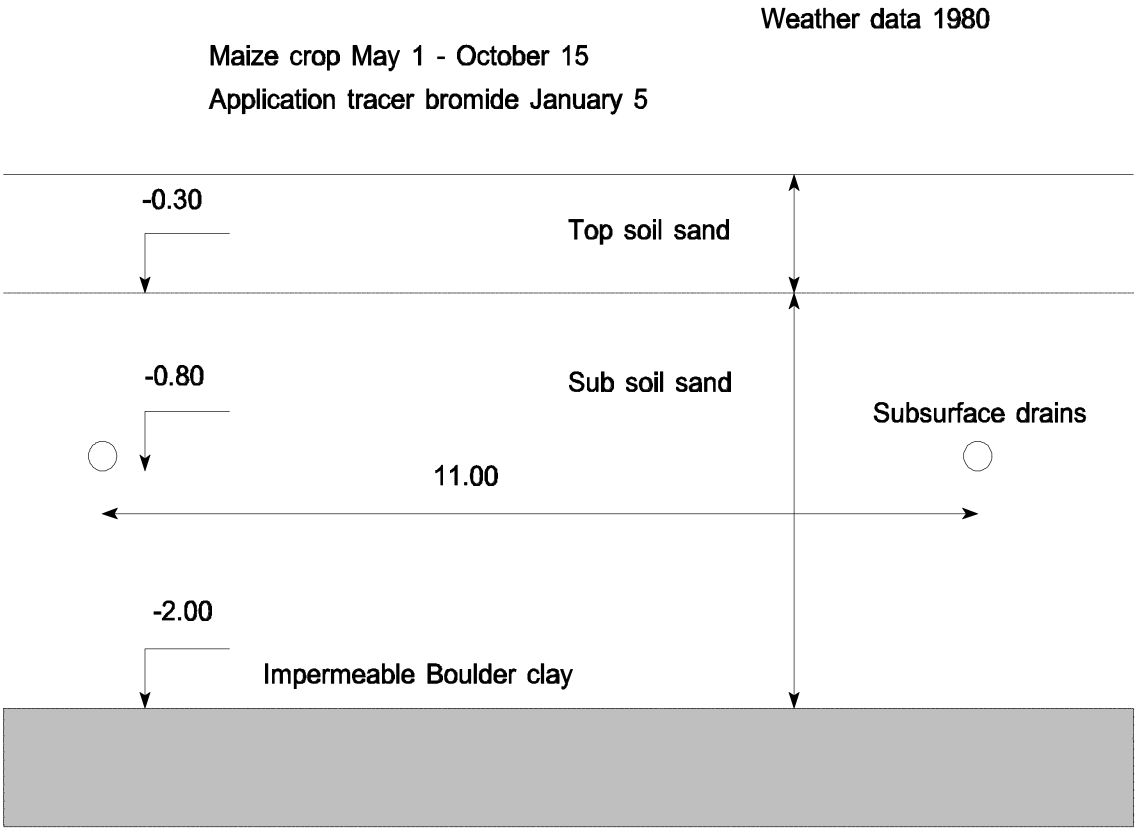


Fig. 7 The schematisation of the Hupsel reference case

Table 3. Maize crop data for the reference situation in the Hupsel catchment.

	Development Stage (-)						
	0.0	0.3	0.5	0.7	1.0	1.4	2.0
Leaf Area Index (-)	0.05	0.14	0.61	4.1	5.0	5.8	5.2
Soil Cover (-)	0.05	0.2	0.5	1.0			1.0
Crop Height (cm)	1	15	40	140	170	180	175
Rooting depth (cm)	5	20	50	80	90		100

6.1.2 Solute

On 5 January, 5 mm KBr is applied with a concentration of 1000 mg/cm^3. The dispersion length equals 5 cm. Molecular diffusion is neglected, as it is much smaller than mechanical dispersion at the prevailing soil water fluxes. In case of bromide adsorption and decomposition are zero, which makes bromide very suitable for tracer studies.

6.1.3 Heat

Heat transport is numerically simulated, using the measured daily air temperature as top boundary condition and zero flux as bottom boundary condition.

6.1.4 Output of reference situation

The simulation period lasts from 1 January to 31 December 1980. The simulated water and solute balance are printed at the end of each month. The monthly output includes the simulated soil profile data on water content, pressure head, solute concentration and soil temperatures.

The following output files are generated and listed in annex A:
– Result.wba: Water balance with cumulative data
– Result.inc: Water balance with data for time increments
– Result.bal: Water balance with data cumulative over time and vertical space
– Result.sba: Solute balance
– Result.tep: Soil temperature
– Result.vap: Soil moisture-, solute- and temperature- profiles
– Result.cr1: crop growth status

Furthermore 3 additional files are generated:
– Swap207.log: a file with error messages
– Hfinal.dat: a file with final pressure heads of all compartments
– Suc.cex: an empty file which is only used by the Graphical User Interface

The SWAP output (annex A, file Result.wba) shows that the maize potential transpiration during 1980 equals 29.63 cm, while the maize actual transpiration of this year equals 26.60 cm. The drainage in 1980 amounts 21.39 cm. The groundwater level reaches its maximum at 31 March (-70.0 cm) and its minimum at 30 September (-131.5 cm). The water balance increments (output file Result.inc) show a small amount of irrigation water which is caused by the application of bromide.
Of the 500 mg/cm^2 bromide applied, 39.5 mg/cm^2 has reached the surface water at 31 December. The main amount of bromide is still in the soil profile.
The maize relative yield (annex A, file Result.cr1) amounts 0.90, which is equal to the ratio of actual transpiration and potential transpiration (26.60/29.63).

6.2 Exercises

The exercises are carried out on directory \EXAMPLES\EXERCISE. Each exercise uses the reference situation of the previous paragraph as starting point. Therefore we start with an inialisation by running the batch-file INITIAL.BAT. This batch-file copies the input files of

the reference-situation from directory \EXAMPLES\EXERCISE\INITIAL to the directory \EXAMPLES\EXERCISE.

Each exercise consists of four steps:
a) *Initialise* with reference situation described in par. 6.1 (execute INITIAL.BAT);
b) *Change input* data in input files and save changed input files
c) *Execute a simulation* with SWAP (execute SWAP.BAT)
d) Verify results

The input can be changed in two ways:
1. using a text editor, directly editing the input files;
2. using the graphical user interface.

Additional input files required for some of the exercises are located on the directory \EXAMPLES\EXERCISE.

6.2.1 Meteorological year

In the first exercise we evaluate the effect of a different meteorological year.
a) *Initialise* with the reference situation described in par. 6.1 (execute INITIAL.BAT);
b) *Change input*:
   1. Select the relatively wet year 1981 by the following changes in the file 'Swap.key' (section 2):
      – the simulation period must be changed to the period 1 January 1981 until 31 December 1981;
      – the output dates must be changed accordingly (note that February has 28 days in 1981).
   2. Goto Key. Load 'SwapGui.key' on directory c:\swap\examples\exercise. The following changes in section Timing have to be carried out:
      – the simulation period must be changed to the period 1 January 1981 until 31 December 1981;
      – the output dates must be changed accordingly (note that February has 28 days in 1981).
c) *Execute a simulation* with SWAP
d) *Verify results*. In the file 'Result.wba' compare rainfall, transpiration, evaporation, drainage and groundwater levels for 31 March, 31 July and 30 November between 1980 (reference situation from par. 6.1) and 1981. Also check bromide amounts leached to surface water in file 'Result.sba'.

Answer

Fluxes	*1980*	*1981*	*Unit*
Rainfall	*66.0*	*79.9*	*cm/year*
Potential transpiration	*29.6*	*27.7*	*cm/year*
Actual transpiration	*26.6*	*26.9*	*cm/year*
Potential evaporation	*35.0*	*29.9*	*cm/year*
Actual evaporation	*14.4*	*14.9*	*cm/year*
Drainage	*21.4*	*33.0*	*cm/year*

Groundwaterlevels	*1980*	*1981*	
31 March	*-70.0*	*-67.4*	*cm*
31 July	*-78.5.*	*-91.9*	*cm*
30 November	*-107.5*	*-65.6*	*cm*

Leaching bromide to drain	*1980*	*1981*	
31 July	*39.3*	*60.0*	*mg/cm²*
31 December	*39.5*	*107.8*	*mg/cm²*

6.2.2 Irrigation

This exercise shows how SWAP can be used to optimize irrigation. The exercise consists of three parts:
6.2.2.1: an imaginary year without rainfall;
6.2.2.2: several years without rainfall
6.2.2.3: surface irrigation
Only the first of these 3 exercises must be initialised; the other 2 exercises continue with the results of the previous exercise.

6.2.2.1 An imaginary year without rainfall

An imaginary year 2000 without rainfall will be simulated first.

a) *Initialise* with reference situation described in par. 6.1 (execute INITIAL.BAT);
b) *Change input*.
   1. In the file ‘Swap.key’ (section 2) the simulation period must be changed to 1 January 2000 - 31 December 2000 and the output dates must be changed accordingly (be aware that the year 2000 is a leap year).
   2. Load 'SwapGui.key' on directory c:\swap\examples\exercise. In section Timing the simulation period must be changed to 1 January 2000 - 31 December 2000 and the output dates must be changed accordingly (be aware that the year 2000 is a leap year).
c) *Execute a simulation*
d) *Verify results*. In the output file 'Result.wba' compare transpiration, evaporation, drainage and groundwater levels for 31 March, 31 July and 30 September between 1980 and 2000. Also check bromide amounts leached to surface water in the output file 'Result.sba'.

Answer

Fluxes	*1980*	*2000*	*Unit*
Potential transpiration	*29.6*	*30.7*	*cm/year*
Actual transpiration	*26.6*	*27.1*	*cm/year*
Potential evaporation	*35.0*	*35.0*	*cm/year*
Actual evaporation	*14.4*	*4.4*	*cm/year*
Drainage	*21.4*	*0.9*	*cm/year*

Groundwaterlevels	*1980*	*2000*	*Unit*
31 March	*-70.0*	*-87.9*	*cm*
31 July	*-78.5*	*-136.1*	*cm*
30 September	*-131.5*	*-174.2*	*cm*

Leaching bromide to drain	*1980*	*2000*	*Unit*
31 July	*39.3*	*0.00*	*mg/cm^2*
31 December	*39.3*	*0.00*	*mg/cm^2*

Although no rainfall occurred in this year, the maize crop is able to transpire 27.1 cm water out of a demand of 30.7 cm. The crop survives because of the large initial water content. This shows the importance of correct initial moisture conditions for water balance analysis.

6.2.2.2 Several years without rainfall

We will see what happens if the period without precipitation continues for a second year.

a) *Change input*.
   1. In the file 'swap.key' changes must be made in 2 sections:
      – Section 2 (Time variables): The simulation period must be changed. Extend the simulation period until 31 December 2001 and set output dates at the end of each month in each year.
      – Section 4 (Input and output files): Specify the input files for the second year for fixed irrigation (''), crop rotation ('Year80'), drainage ('Hupsel') and bottom boundary condition ('Hupsel'). In this way the boundary conditions are the same as the first year, except that the bromide tracer is only applied the first year. Specify the generic name for the output files for year 2001 as 'Result2'.
   2. Goto Key. Load 'SwapGui.key' on directory c:\swap\examples\exercise. Change the following:
      – At section Timing: Extend the simulation period to 1 January 2000 - 31 December 2001 and set output dates at the end of each month in each year.
      – At section Sub-runs: Specify the input files for the second year for fixed irrigation (''), crop rotation ('Year80'), drainage ('Hupsel') and bottom boundary condition ('Hupsel'). In this way the boundary conditions are the same as the first year, except that the bromide tracer is only applied the first year. Specify the generic name for the output files for year 2001 as 'Result2'.

b) *Execute a simulation*

c) *Verify results.* Compare transpiration and evaporation for 2000 and 2001 (files 'Result.wba' and 'Result2.wba'). Also compare relative crop yield for both years (files 'Result.cr1' and 'Result2.cr1')

Answer

Fluxes	*2000*	*2001*	*Unit*
Potential transpiration	*30.7*	*30.8*	*cm/year*
Actual transpiration	*27.1*	*12.2*	*cm/year*
Potential evaporation	*35.0*	*34.9*	*cm/year*
Actual evaporation	*4.4*	*1.7*	*cm/year*

Crop growth	*2000*	*2001*	*Unit*
Relative yield	*0.88*	*0.40*	*-*

The crop in the second year can only transpire 40% of the potential transpiration, which will severely hamper crop development.

6.2.2.3 Surface irrigation

This exercise shows what will happen if the previous simulation is continued automatic irrigation scheduling for both years.

a) *Change input.*
   1. Specify in the crop calendar file 'Year80.cal' (variabel CAPFIL) the input file for irrigation scheduling ('Irrig.cap') and set emergence data at 1st of May. Verify (no changes required !) in the input file 'Irrig.cap' (Section 2) the Ratio for allowable Daily Stress (Ta/Tp), which should be equal to 0.95 during the entire growing period. Also verify in the same file 'Irrig.cap' (Section 3) the irrigation depth criterium which should be Back to Field Capacity without under- or over-irrigation.
   2. Goto Crop/calendar. Load file 'Year80.cal'. Specify the input file for irrigation scheduling ('Irrig.cap') and set start date of irrigation at 1st of May.
      Goto Irrigations/scheduled irrigations. Load file 'Irrig.cap'. Verify (no changes required !) at section Timing Criteria, the Ratio for allowable Daily Stress: Ta/Tp = 0.95 during the entire growing period. Also verify at section Depth Criteria, the irrigation depth criterium which must be Back to Field Capacity without under- or over-irrigation.

b) *Execute a simulation*

c) *Verify results.* Analyse irrigation, transpiration, evaporation, drainage, and crop yield for the years 2000 and 2001.

Answer

Fluxes	*2000*	*2001*	*Unit*
Irrigation	*14.0*	*27.8*	*cm/year*
Potential transpiration	*30.7*	*30.8*	*cm/year*
Actual transpiration	*30.5*	*30.3*	*cm/year*
Potential evaporation	*35.0*	*34.9*	*cm/year*
Actual evaporation	*6.5*	*5.9*	*cm/year*
Drainage	*0.9*	*0.0*	*cm/year*

Crop growth	*2000*	*2001*	*Unit*
Relative yield	*0.99*	*0.99*	*-*

In the second year almost double the amount of irrigation water is needed, due to the decrease of water storage in the soil profile. The used irrigation criterium increases the relative crop yield to 0.99 in both years. If water has to be saved, a more stringent irrigation criterium can be considered.

6.2.3 Crop type

In this exercise the water balance for grassland instead of the maize crop will be simulated using the simple crop growth model.

a) *Initialise* with reference situation described in par. 6.1 (execute INITIAL.BAT);

b) *Change input*.

1. In the crop calendar file 'Year80.cal' change the name of the crop data file CRPFIL, to 'GrassS'. In the same file choose the simple crop type model (Type =1) and set the

emergence date at 1 January and the end date at 31 December. Verify the crop data in the file 'GrassS.crp': the leaf area index LAI = 2.5, soil cover SC = 1.0, crop height CH = 15 cm, and rooting depth RD = 40 cm, during the whole year 1980. You might check the pressure heads of the reduction function for root water extraction with Annex C (Van Dam, 1997).

2. Goto Crop/calendar. Load file 'Year80.cal'. Change file with crop parameters to GrassS. In this case we will also use the simple crop model. Set the emergence date at 1 January and the harvest date at 31 December.
   Goto Crop/data/simple model. Load file 'grass.crp'. Verify (don't change !) the crop data: the leaf area index LAI = 2.5, soil cover SC = 1.0, crop height CH = 15 cm, and rooting depth RD = 40 cm, during the whole year 1980.

c) *Execute a simulation*
d) *Verify results.* Compare interception, transpiration, evaporation, and drainage between the maize and grass cro p for the year 1980.

Answer

Fluxes	*Maize*	*Grass*	*Unit*
Interception	*4.5*	*7.4*	*cm/year*
Potential transpiration	*29.6*	*54.9*	*cm/year*
Actual transpiration	*26.6*	*54.9*	*cm/year*
Potential evaporation	*35.0*	*0.0*	*cm/year*
Actual evaporation	*14.4*	*0.0*	*cm/year*
Drainage	*21.4*	*9.6*	*cm/year*

Grass covers the soil the year round, which cause, compared to maize, a larger interception and actual transpiration, and a smaller actual evaporation and drainage.

6.2.4 Evapotranspiration of partly covered soil

The potential evapotranspiration demand as exerted by the atmosphere has to be divided into potential transpiration and potential evaporation (see Par. 6.6, Van Dam, 1997). This division can be based on the leaf area index or the soil cover. As the reduction of potential transpiration is generally much less than the reduction of potential evaporation, the water balance is quite sensitive to the method used to divide potential transpiration and potential evaporation. In this exercise we change the method of division and evaluate the effect on the simulated water balance.

a) *Initialise* with reference situation described in par. 6.1 (execute INITIAL.BAT);
b) *Change input*:

1. Use soil cover data to divide potential evapotranspiration into potential transpiration and potential evaporation. Therefore you must change in the crop data file 'MaizeS.crp', section 4, the variable SWSC to a value of 1. Verify whether the soil cover data (variable SC) correspond to data given in par. 6.1, table 3.
2. Goto Crop/data/simple model. Load file 'MaizeS.crp'. At page 2, select to use soil cover data to divide potential evapotranspiration into potential transpiration and potential evaporation. Supply the soil cover data as specified in par. 6.1, table 3.

c) *Execute a simulation*
d) *Verify results.* Compare transpiration, evaporation, and drainage for the simulation that uses the leaf area index (reference) and the simulation that uses the soil cover to divide the potential evapotranspiration.

Answer

Fluxes	*LAI*	*SC*	*Unit*
Potential transpiration	*29.6*	*35.5*	*cm/year*
Actual transpiration	*26.6*	*33.0*	*cm/year*
Potential evaporation	*35.0*	*29.6*	*cm/year*
Actual evaporation	*14.4*	*11.4*	*cm/year*
Drainage	*21.4*	*18.1*	*cm/year*

The simulated water balance for both cases is clearly different. A proper division of potential evapotranspiration in potential transpiration and potential evaporation is needed to achieve an accurate water balance.

6.2.5 Soil texture

During this exercise you will investigate the effect of changes in soil texture.

a) *Initialise* with reference situation described in par. 6.1 (execute INITIAL.BAT);
b) *Change input*:
   1. Two changes are needed:
      – Change in the soil water file 'Hupsel.swa', section 5, the names of hydraulic function files to 'Clayt' (clay - top soil) and 'Clays' (clay - sub soil).
      – Change in the input file ‘Hupsel.drb’, section 3, variable KHTOP, the saturated conductivity for a calculation of the drainage flux from 25 to 2.5 cm/d.
   2. Two changes are needed:
      – Goto Soil/Profile description. Load file 'Hupsel.swa'. At page 2, change the names of the files with the soil hydraulic functions. The first layer should be 'Clayt' (clay - top soil) and the second layer 'Clays' (clay - sub soil).
      – Goto Drainage/basic. Load file 'Hupsel.drb'. Change the horizontal hydraulic conductivity of the top layer from 25 to 2.5 cm/d.
c) *Execute a simulation*
d) *Verify results.* Verify runoff, transpiration, drainage and groundwater levels at 31 March, 31 July and 30 September for the simulations with the sand and the clay soil.

Answer

Fluxes	*Sand*	*Clay*	*Unit*
Runoff	*0.0*	*12.6*	*cm/year*
Potential transpiration	*29.6*	*29.6*	*cm/year*
Actual transpiration	*26.6*	*22.5*	*cm/year*
Drainage	*21.4*	*11.9*	*cm/year*

Groundwaterlevels	*Sand*	*Clay*	*Unit*
31 March	*-70.0*	*-29.2*	*cm*
31 July	*-78.5*	*-65.6*	*cm*
30 September	*-131.5*	*-162.1*	*cm*

Although daily values for precipitation are used, runoff occurs at the clay soil. The higher groundwater levels in the clay soil during the growing season, cause less root water uptake at the deeper soil layers, and thus less actual transpiration. In the second half of the year, the groundwater levels decline, because less water percolates to the groundwater.

6.2.6 Hysteresis of retention function

During this exercise you will include hysteresis of the retention function and check its effect on the soil water balance.

a) *Initialise* with reference situation described in par. 6.1 (execute INITIAL.BAT);
b) *Change input*:
   1. Choose the hysteresis option by changing in the soil water file 'Hupsel.swa', section 6, the variable SWHYST. As we start the simulation in a wet period during winter, we should start from the main drying curve; therefore the variable SWHYST must be 2. Next we need to specify the α_w parameter of the Mualem - Van Genuchten function to calculate the main wetting curve (see Par. 2.2.3, Van Dam, 1997). This parameter should be specified in both soil files ('Sandt.sol' and 'Sands.sol'). As a rule of the thumb, take $\alpha_w = 2\ \alpha_d$. You may verify the values of these parameters (file *.sol, section 3, COFGEN4 and COFGEN8), but you don't need to change these values as they have defined already.
   2. Goto Soil/Profile description. Load file 'Hupsel.swa'. At page 3, select hysteresis with initial condition drying. As we start the simulation in a wet period in winter, we should start from the main drying curve. Next we need to specify the αw parameter of the Mualem - Van Genuchten function to calculate the main wetting curve (see Par. 2.2.3, Van Dam, 1997). Goto Soil/layer: hydraulic properties. Load file 'Sandt.sol'. As a rule of the thumb, take the parameter 'alpha main wetting' equal to twice the value of 'alpha main drying'. Do the same for the second soil layer ('Sands.sol').

c) *Execute a simulation*
d) *Verify results* Analyse the effect of hysteresis on transpiration, evaporation, drainage and groundwater levels at 31 March and 30 September.

Answer

Fluxes	*No Hyst.*	*With Hyst.*	*Unit*
Potential transpiration	*29.6*	*29.6*	*cm/year*
Actual transpiration	*26.6*	*26.6*	*cm/year*
Potential evaporation	*35.0*	*35.0*	*cm/year*
Actual evaporation	*14.4*	*14.4*	*cm/year*
Drainage	*21.4*	*22.7*	*cm/year*

Groundwaterlevels	*No Hyst.*	*With Hyst.*	*Unit*
31 March	*-70.0*	*-70.5*	*cm*
30 September	*-131.5*	*-129.7*	*cm*

At the present hydrological conditions, hysteresis hardly affects the water balance and groundwater levels.

6.2.7 Scaling of soil hydraulic functions

Horizontal variability of the soil hydraulic functions can be taken into account by scaling according to Miller and Miller (see Par. 5.1.2, Van Dam, 1997). In SWAP you may supply up to 30 scaling factors. The program will generate the actual soil hydraulic functions out of the reference soil hydraulic functions and perform a simulation for each plot. Just to

practise how this works, we will use three scaling factors: 0.45, 1.00 and 2.50. The second simulation with scaling factor 1.00 corresponds to the reference simulation.

a) *Initialise* with reference situation described in par. 6.1 (execute INITIAL.BAT);

b) *Change input*:
   1. In file 'Hupsel.swa', section 7, choose the option scaling for 3 repetitions and apply the scaling to the top layer. Supply the three scaling factors: 0.45, 1.00 and 2.50.
   2. Goto Soil/Profile description. Load file ‘Hupsel.swa’. At page 3, select scaling. Set number of repetitions to 3, number of soil layers involved to 1, and supply the three scaling factors: 0.45, 1.00 and 2.50.

c) *Execute a simulation*

d) *Verify results.* Check that the second simulation indeed corresponds to the reference simulation. Evaluate transpiration, evaporation, drainage and groundwater levels for the three simulations.

Answer

Scaling factor	*0.45*	*1.00*	*2.50*	*Unit*
Runoff	*0.6*	*0.0*	*0.0*	*cm/year*
Potential transpiration	*29.6*	*29.6*	*29.6*	*cm/year*
Actual transpiration	*26.9*	*26.6*	*26.6*	*cm/year*
Potential evaporation	*35.0*	*35.0*	*35.0*	*cm/year*
Actual evaporation	*14.4*	*14.4*	*14.4*	*cm/year*
Drainage	*21.5*	*21.4*	*21.1*	*cm/year*
Groundwaterlevels				
31 March	*-69.8*	*-70.0*	*-69.9*	*cm*
30 September	*-137.0*	*-131.5*	*-131.9*	*cm*

The results with the three scaling factors show, that the water balance is not sensitive to the soil texture. The water balance is mainly governed by the boundary conditions.

6.2.8 Root density distribution

In the reference simulation (par. 6.1), a triangular root density distribution was assumed. In general the root density will decrease with depth, especially in case of irrigation, shallow groundwater tables, decreasing organic matter content and increasing mechanical resistance.
This exercise will show the effect of changes in the root density distribution.

a) *Initialise* with reference situation described in par. 6.1 (execute INITIAL.BAT);

b) *Change input*:
   1. In the file 'MaizeS.crp', section 11, variable Rdensity, change the root density distribution from triangular to uniform (set all values for Rdensity to 1.0).
   2. Goto Crop/data/simple model. Load file 'MaizeS.crp'. At page 1, section Root distribution, set Rdens = 1.0 for 0.0 ≤ Rdepth ≤ 1.0. In this way a uniform root distribution is defined.

c) *Execute a simulation*

d) *Verify results.* Analyse transpiration, evaporation, drainage and groundwater levels for the triangular and uniform root density distribution.

Answer

Fluxes	*Triangular*	*Uniform*	*Unit*
Potential transpiration	*29.6*	*29.6*	*cm/year*
Actual transpiration	*26.6*	*21.6*	*cm/year*
Potential evaporation	*35.0*	*35.0*	*cm/year*
Actual evaporation	*14.4*	*14.4*	*cm/year*
Drainage	*21.4*	*25.1*	*cm/year*

Groundwaterlevels	*Triangular*	*Uniform*	*Unit*
31 March	*-70.0*	*-70.0*	*cm*
30 November	*-107.5*	*-87.5*	*cm*

In case of the uniform root distribution, the actual transpiration sharply reduces to 21.6 cm. A large reduction occurs in the lower, wet part of the root zone. In the current model concept, water stress at a certain soil depth is not compensated for by higher root water uptake at another soil depth. Therefore, in case of shallow groundwater levels, be sure that the appropriate rooting depth and -distribution are used!

6.2.9 Bromide breakthrough to surface water

Tracer studies in the field that include both the unsaturated and saturated zone may require a duration of several years. In the reference situation (par. 6.1), after one year, only 39.5 mg/cm^2 out of 500 mg/cm^2 is leached to the drains. After one year, only a small amount of bromide has reached the groundwater level, which you may verify from the solute profiles in output file 'Result.vap'.

In this exercise we will simulate bromide leaching in the second experimental year. Also we will analyse the influence of the depth of the impervious layer.

6.2.9.1 Breakthrough during a 2-year period

During this first part of the exercise you will calculate the breakthrough of the bromide during a two-year period.

a) *Initialise* with reference situation described in par. 6.1 (execute INITIAL.BAT);
b) *Change input*.
   1. In the file ‘Swap.key’ changes must be made in 2 sections:
      – Section 2 (Time variables): extend the simulation period to 31 December 1981 and specify monthly output dates for the years 1980 and 1981 (1981 is no leap year).
      – Section 4 (Input and output files): Specify the input files for the second year for fixed irrigation (''), crop rotation ('Year80'), drainage ('Hupsel') and bottom boundary condition ('Hupsel'). In this way the boundary conditions are the same as the first year, except that the bromide tracer is only applied the first year. Specify the generic name for the output files for the year 1981 as 'Result2'.
   2. Goto Key and load file 'SwapGui.key'. Changes must be made in 2 sections:
      – In section Timing, set the end of the simulation period to 31 December 1981 and specify output dates at the end of each month for 1981 (no leap year);

– In section Subruns, specify the input files for the second year for fixed irrigation (''), crop rotation ('Year80'), drainage ('Hupsel') and bottom boundary condition ('Hupsel'). In this way the boundary conditions are the same as the first year, except that the bromide tracer is only applied the first year. Specify the generic name for the output files for the year 1981 as 'Result2'.

c) *Execute a simulation*

d) *Verify results.* Verify leaching of bromide for 1980 and 1981 (files 'Result.bal' and 'Result2.bal'). How much bromide leached to the drains on 31 December 1981 ?

Answer

Year	*Bromide leached*	*Unit*
1980	*39.5*	*mg/cm^2*
1981	*197.1*	*mg/cm^2*

The bromide leaches very slowly to the ditches. Although at the start of the first year 500 mg/cm^2 bromide has been applied to the field, after two year only 39.5 + 197.1 = 236.6 mg/cm^2 bromide has leached to the ditches.

6.2.9.2 Influence of an impervious soil layer

The residence time of pesticides and nutrients in the vadose zone is very important for decomposition and uptake by roots. In the saturated zone mainly dilution of solutes occurs. The residence time of solutes in the saturated zone, however, can be considerable. In the reference case (par. 6.1), an impermeable layer occurs at 2 m depth, which results in a relatively small residence time.
During this second part the sensitivity of the bromide breakthrough to the impermeable layer depth will be analysed. You will be using the results of the previous paragraph as reference.

a) *Change input*:

1. Two files need changes:
   – File ‘Hupsel.drb’, section 3, variable BASEGW: change the depth of the impermeable layer (BASEGW) from -200 to -180 cm;
   – File ‘Hupsel.swa’, section 4, variables NUMNOD and BOTCOM(2): change the number of compartments NUMNOD from 34 to 32, and the bottom compartment of the secondlayer BOTCOM(2) from 34 to 32.
2. Two files need changes:
   – Goto Drainage/basic, and load file' Hupsel.drb'. Change the depth of the impermeable layer from -200 to -180 cm;
   – Goto Soil/profile description, and load file 'Hupsel.swa'. At page 2, change the number of soil compartments to 32. Also change the compartment at the bottom of the second layer from 34 to 32.

b) *Execute a simulation*

c) *Verify results.* Verify leaching of bromide for 1980 and 1981 (files 'Result.bal' and 'Result2.bal'). How much bromide is leached to the drains on 31 December 1980 and 1981 ?

Answer

	Depth impermeable layer (m)		
Year	*-2.00*	*-1.80*	*Unit*
During 1980	*39.5*	*46.3*	*mg/cm²*
During 1981	*197.1*	*216.1*	*mg/cm²*

In the first year, an increase of the impermeable layer with 0.20 m increases the bromide leaching from 39.5 to 46.3 mg/cm^2 (+17%). This may be important in case of pesticides. In the second year the effect of the height of the impermeable layer is less (+10%).

6.2.10 Preferential flow

Field tracer studies may be affected by preferential flow due to water repellency or clay cracks. In this exercise we will consider preferential flow due to water repellency in the top soil layer, which may have a large impact on bromide leaching to the surface water. We will assume that in the water repellent top layer the flow paths occupy only 40 percent of the soil volume.

a) *Initialise* with reference situation described in par. 6.1 (execute INITIAL.BAT);

b) *Change input*.

1. Change in the file 'Hupsel.swa', section 8, variable SWMOBI; enable preferential flow by setting the variable SWMOBI to 1. Verify that the mobile fraction 0.4 in the first soil layer and 1.0 in the second soil layer, and the volumetric water content in the immobile soil volume fraction = 0.02 (THETIM). The corresponding input table in section 8, is then looking as listed under 2.
2. Goto Soil/profile description. At page 3, section preferential flow, include immobile water. In the Table, specify the following values for the 2 soil layers:

PF1	FM1	PF2	FM2	THETIM
0.0	0.4	3.0	0.4	0.02
0.0	1.0	3.0	1.0	0.02

c) *Execute a simulation*

d) *Verify results.* Compare the amount of bromide leached in 1980 for the case with uniform flow and the case with preferential flow.

Answer

Bromide leached	*Uniform flow*	*Preferential flow*	*Unit*
During 1980	*39.5*	*68.2*	*mg/cm²*

The results show that preferential flow due to water repellency has a large impact on the leaching of bromide.

6.2.11 Drainage design

Drainage design, taking into account transient flow conditions, is an important feature of SWAP. For instance, SWAP allows a design that accounts for capillary rise, which decreases the required irrigation demands. The program also allows optimization of

irrigation time and application of irrigation amounts that take into account a certain amount of leaching.
In this exercise we will just explore whether the drainage depth in the Hupsel reference situation (par.6.1) is optimal for the weather conditions in 1980.

First we need to determine whether the reduction of maize growth is determined by either too wet or too dry conditions.

6.2.11.1 Reduction for wet conditions

a) *Initialise* with reference situation described in par. 6.1 (execute INITIAL.BAT);
b) *Change input*.
   1. Change in the crop file ‘MaizeS.crp’, section 8, the variables HLIM1, HLIM2U, HLIM2L (these parameters determine the wet branch of the root water uptake reduction fucntion) to +100 cm. By specifying this positive value, the simulated maize crop will never suffer from too wet conditions.
   2. Goto Crop/data/simple model, and load file 'MaizeS.crp'. At page 3, change the pressure head values to + 100 cm for 'start to extract water from the soil', 'start to extract water optimally from the upper soil layer', and 'start to extract water optimally from the lower soil layers'. In this way the wet branch of the root water uptake reduction function is eliminated, and the simulated maize crop will never suffer from too wet conditions.
c) *Execute a simulation*
d) *Verify results.* Compare the transpiration for the cases with and without reduction at too wet conditions.

Answer

Reduction at too wet conditions	*Yes*	*No*	*Unit*
Potential transpiration	*29.6*	*29.6*	*cm/year*
Actual transpiration	*26.6*	*29.6*	*cm/year*

By excluding the stress due to wet conditions, the actual transpiration becomes equal to the potential transpiration. Probably stress due to wetness occurs and the drains are too high or the spacing is too wide for this particular year.

6.2.11.2 Increasing drain depth

a) *Initialise* with reference situation described in par. 6.1 (execute INITIAL.BAT);
b) *Change input*:
   1. Change in the crop file ‘Hupsel.drb’, section 3, the variable ZBOTDR; decrease the drain level (ZBOTDR) from -80.0 cm to -100.0 cm. Change in the file 'Hupsel.swa', section 11, the initial groundwater level (GWLI) from -75 to -95 cm.
   2. Goto Drainage/basic, and load file 'Hupsel.swa'. Decrease the drain level from -80.0 cm to -100.0 cm. Goto Soil/profile description, and load file 'Hupsel.swa'. Decrease the initial groundwater level from -75 to -95 cm.
c) *Execute a simulation*
d) *Verify results.* Compare the transpiration, evaporation, drainage and groundwater levels for the simulations with both drain depths.

Answer

Drain depth (cm)	*-80.0*	*-100.0*	*Unit*
Potential transpiration	*29.6*	*29.6*	*cm/year*
Actual transpiration	*26.6*	*28.7*	*cm/year*
Potential evaporation	*35.0*	*35.0*	*cm/year*
Actual evaporation	*14.4*	*14.4*	*cm/year*
Drainage	*21.4*	*19.4*	*cm/year*
Groundwaterlevels			
31 March	*-70.0*	*-90.3*	*cm*
30 September	*-131.5*	*-144.4*	*cm*
Crop yield	*0.90*	*0.97*	*-*

For the year 1980 a change of the drain depth from -80 to -100 cm, would increase to actual transpiration from 26.6 to 28.7 cm, and increase the relative crop yield from 0.90 to 0.97. Simulations for a range of years are needed to determine the optimal drainage depth for this field.

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Annex A. Output files of the Hupsel reference case

Output file Result.bal

```
Period            :  1/01/1980 until  31/12/1980
Depth soil profile :  200.00 cm

            Water storage         Solute storage
Final   :        71.63 cm       0.4605E+03 mg/cm2
Initial :        72.07 cm       0.0000E+00 mg/cm2
            =============       =================
Change          -0.44 cm       0.4605E+03 mg/cm2


Water balance components (cm)

In                            Out
=========================     ============================
Rain            :    66.01    Interception      :     4.52
Irrigation      :     0.50    Runoff            :     0.00
Bottom flux     :     0.00    Transpiration     :    26.60
                              Soil evaporation  :    14.43
                              Crack flux        :     0.00
                              Drainage level 1  :    21.39
=========================     ============================
Sum             :    66.51    Sum               :    66.95


Solute balance components (mg/cm2)

In                            Out
=========================     ============================
Rain        :  0.0000E+00     Decomposition  :  0.0000E+00
Irrigation  :  0.5000E+03     Root uptake    :  0.0000E+00
Bottom flux :  0.0000E+00     Cracks         :  0.0000E+00
                              Drainage       :  0.3950E+02
=========================     ============================
Sum         :  0.5000E+03     Sum            :  0.3950E+02
```

Output file Result.inc

```
Water balance increments (cm/period)

*      Date Day    Rain   Irrig  Interc  Runoff   Transpiration     Evaporation Drainage QBottom
*dd/mm/yyyy  nr                                     pot     act     pot     act
<=========><==><======><======><======><======><======><======><======><======><=======><======>
 31/01/1980  31   4.690   0.500   0.000   0.000   0.000   0.000   0.564   0.546    3.316   0.000
 29/02/1980  60   4.650   0.000   0.000   0.000   0.000   0.000   1.645   1.151    5.133   0.000
 31/03/1980  91   5.490   0.000   0.000   0.000   0.000   0.000   3.319   1.843    2.371   0.000
 30/04/1980 121   4.060   0.000   0.000   0.000   0.000   0.000   6.376   2.273    3.049   0.000
 31/05/1980 152   0.930   0.000   0.013   0.000   0.068   0.068  11.985   1.107    0.220   0.000
 30/06/1980 182   6.620   0.000   0.796   0.000   3.633   3.535   5.682   2.193    0.359   0.000
 31/07/1980 213  14.570   0.000   1.424   0.000   7.370   4.905   1.056   1.056    6.884   0.000
 31/08/1980 244   4.640   0.000   1.076   0.000   9.516   9.062   0.757   0.757    0.006   0.000
 30/09/1980 274   2.740   0.000   0.829   0.000   7.063   7.053   0.484   0.484    0.000   0.000
 31/10/1980 305   6.740   0.000   0.383   0.000   1.981   1.981   1.180   1.152    0.000   0.000
 30/11/1980 335   5.260   0.000   0.000   0.000   0.000   0.000   1.274   1.192    0.000   0.000
 31/12/1980 366   5.620   0.000   0.000   0.000   0.000   0.000   0.720   0.678    0.055   0.000
```

Output file Result.wba

```
*      DATE DAY    RAIN [cm]     IRR [cm]      RUO    TRA [cm]      EVS [cm]      FLUX [cm]      DSTOR     GWL  QDIF      Date*
*dd/mm/yyyy  nr    gro....net   gro...net      cm    pot....act    pot....act     lat.....bot      cm      cm    cm dd/mm/yyyy
*<========><==><=====><=====><====><====><======><=====><=====><=====><=====><======><======><======><======><====><=========>
 31/01/1980  31   4.69   4.69   0.5   0.5    0.00   0.00   0.00   0.56   0.55    3.32    0.00    1.33   -73.1  0.00 31/01/1980
 29/02/1980  60   9.34   9.34   0.5   0.5    0.00   0.00   0.00   2.21   1.70    8.45    0.00   -0.31   -76.8  0.00 29/02/1980
 31/03/1980  91  14.83  14.83   0.5   0.5    0.00   0.00   0.00   5.53   3.54   10.82    0.00    0.97   -70.0  0.00 31/03/1980
 30/04/1980 121  18.89  18.89   0.5   0.5    0.00   0.00   0.00  11.90   5.81   13.87    0.00   -0.29   -77.0  0.00 30/04/1980
 31/05/1980 152  19.82  19.81   0.5   0.5    0.00   0.07   0.07  23.89   6.92   14.09    0.00   -0.77   -81.2  0.00 31/05/1980
 30/06/1980 182  26.44  25.63   0.5   0.5    0.00   3.70   3.60  29.57   9.11   14.45    0.00   -1.03   -82.3  0.00 30/06/1980
 31/07/1980 213  41.01  38.78   0.5   0.5    0.00  11.07   8.51  30.63  10.17   21.33    0.00   -0.73   -78.5  0.00 31/07/1980
 31/08/1980 244  45.65  42.34   0.5   0.5    0.00  20.59  17.57  31.38  10.93   21.34    0.00   -7.00  -116.4  0.00 31/08/1980
 30/09/1980 274  48.39  44.25   0.5   0.5    0.00  27.65  24.62  31.87  11.41   21.34    0.00  -12.62  -131.5  0.00 30/09/1980
 31/10/1980 305  55.13  50.61   0.5   0.5    0.00  29.63  26.60  33.05  12.56   21.34    0.00   -9.40  -128.0  0.00 31/10/1980
 30/11/1980 335  60.39  55.87   0.5   0.5    0.00  29.63  26.60  34.32  13.76   21.34    0.00   -5.33  -107.5  0.00 30/11/1980
 31/12/1980 366  66.01  61.49   0.5   0.5    0.00  29.63  26.60  35.04  14.43   21.39    0.00   -0.44   -78.8  0.00 31/12/1980
```

Output file Result.sba

```
*DATE       DAY      SQTOP      DECTOT      ROTTOT      SAMPRO      SAMCRA       SQBOT       SQDRA       SQRAP       SAMAQ       SQSUR    SOLBAL*

*dd/mm/yyyy  nr      mg/cm2      mg/cm2      mg/cm2      mg/cm2      mg/cm2      mg/cm2      mg/cm2      mg/cm2      mg/cm2      mg/cm2    mg/cm2*
*<========><==><==========><==========><==========><==========><==========><==========><==========><==========><==========><==========><=========>
 31/ 1/1980  31  0.5000E+03  0.0000E+00  0.0000E+00  0.5000E+03  0.0000E+00  0.0000E+00  0.7371E-06  0.0000E+00  0.0000E+00  0.0000E+00  -0.73E-03
 29/ 2/1980  60  0.5000E+03  0.0000E+00  0.0000E+00  0.4996E+03  0.0000E+00  0.0000E+00  0.3522E+00  0.0000E+00  0.0000E+00  0.0000E+00  -0.18E-02
 31/ 3/1980  91  0.5000E+03  0.0000E+00  0.0000E+00  0.4992E+03  0.0000E+00  0.0000E+00  0.7961E+00  0.0000E+00  0.0000E+00  0.0000E+00  -0.20E-02
 30/ 4/1980 121  0.5000E+03  0.0000E+00  0.0000E+00  0.4970E+03  0.0000E+00  0.0000E+00  0.2961E+01  0.0000E+00  0.0000E+00  0.0000E+00  -0.29E-02
 31/ 5/1980 152  0.5000E+03  0.0000E+00  0.0000E+00  0.4969E+03  0.0000E+00  0.0000E+00  0.3075E+01  0.0000E+00  0.0000E+00  0.0000E+00  -0.32E-02
 30/ 6/1980 182  0.5000E+03  0.0000E+00  0.0000E+00  0.4966E+03  0.0000E+00  0.0000E+00  0.3356E+01  0.0000E+00  0.0000E+00  0.0000E+00  -0.35E-02
 31/ 7/1980 213  0.5000E+03  0.0000E+00  0.0000E+00  0.4607E+03  0.0000E+00  0.0000E+00  0.3929E+02  0.0000E+00  0.0000E+00  0.0000E+00  -0.50E-02
 31/ 8/1980 244  0.5000E+03  0.0000E+00  0.0000E+00  0.4607E+03  0.0000E+00  0.0000E+00  0.3931E+02  0.0000E+00  0.0000E+00  0.0000E+00  -0.50E-02
 30/ 9/1980 274  0.5000E+03  0.0000E+00  0.0000E+00  0.4607E+03  0.0000E+00  0.0000E+00  0.3931E+02  0.0000E+00  0.0000E+00  0.0000E+00  -0.50E-02
 31/10/1980 305  0.5000E+03  0.0000E+00  0.0000E+00  0.4607E+03  0.0000E+00  0.0000E+00  0.3931E+02  0.0000E+00  0.0000E+00  0.0000E+00  -0.49E-02
 30/11/1980 335  0.5000E+03  0.0000E+00  0.0000E+00  0.4607E+03  0.0000E+00  0.0000E+00  0.3931E+02  0.0000E+00  0.0000E+00  0.0000E+00  -0.49E-02
 31/12/1980 366  0.5000E+03  0.0000E+00  0.0000E+00  0.4605E+03  0.0000E+00  0.0000E+00  0.3950E+02  0.0000E+00  0.0000E+00  0.0000E+00  -0.48E-02
```

Output file Result.cr1

```
*DATE           ID DVS  LAI  CH  RD  CRT  RELY*
*dd/mm/yyyy  nr              cm  cm          *
*<============><==><===><===><==><==><===><===>
 31/05/1980 152  31 0.37 0.30  24  30 0.99 0.99
 30/06/1980 182  61 0.73 4.18 143  81 0.97 0.97
 31/07/1980 213  92 1.10 5.19 172  91 0.77 0.77
 31/08/1980 244 123 1.46 5.74 179  95 0.85 0.85
 30/09/1980 274 153 1.82 5.38 176  98 0.89 0.89
 15/10/1980 289 168 2.00 5.20 175 100 0.90 0.90

with RELY = relative crop yield
```

Output file Result.vap

```
*       date        depth  water        head     solute  temp        Wflux        Sflux
*                      cm    (-)          cm     mg/cm3     C         cm/d      mg/cm2/d
 31/01/1980  31     -0.5  0.354     -36.684  0.304E+02   7.4  -0.111E+01  -0.338E+02
 31/01/1980  31     -1.5  0.353     -37.105  0.363E+02   7.3  -0.109E+01  -0.396E+02
 31/01/1980  31     -2.5  0.352     -37.527  0.424E+02   7.1  -0.107E+01  -0.455E+02
 31/01/1980  31     -3.5  0.352     -37.948  0.485E+02   7.0  -0.105E+01  -0.511E+02
 31/01/1980  31     -4.5  0.351     -38.367  0.546E+02   6.9  -0.103E+01  -0.563E+02
 31/01/1980  31     -5.5  0.350     -38.780  0.603E+02   6.8  -0.101E+01  -0.609E+02
 31/01/1980  31     -6.5  0.349     -39.185  0.655E+02   6.6  -0.987E+00  -0.646E+02
 31/01/1980  31     -7.5  0.348     -39.580  0.699E+02   6.5  -0.963E+00  -0.673E+02
 31/01/1980  31     -8.5  0.347     -39.962  0.732E+02   6.4  -0.938E+00  -0.687E+02
 31/01/1980  31     -9.5  0.346     -40.328  0.753E+02   6.2  -0.913E+00  -0.687E+02
 31/01/1980  31    -12.5  0.344     -41.433  0.776E+02   5.9  -0.833E+00  -0.647E+02
 31/01/1980  31    -17.5  0.342     -42.513  0.541E+02   5.3  -0.701E+00  -0.380E+02
 31/01/1980  31    -22.5  0.341     -42.696  0.281E+02   4.7  -0.583E+00  -0.164E+02
 31/01/1980  31    -27.5  0.343     -41.962  0.119E+02   4.2  -0.494E+00  -0.587E+01
 31/01/1980  31    -32.5  0.296     -38.592  0.485E+01   3.8  -0.417E+00  -0.202E+01
 31/01/1980  31    -37.5  0.309     -34.353  0.175E+01   3.4  -0.341E+00  -0.597E+00
 31/01/1980  31    -42.5  0.323     -29.838  0.574E+00   3.2  -0.277E+00  -0.159E+00
 31/01/1980  31    -47.5  0.337     -25.139  0.174E+00   2.9  -0.221E+00  -0.385E-01
 31/01/1980  31    -52.5  0.351     -20.322  0.495E-01   2.7  -0.173E+00  -0.858E-02
 31/01/1980  31    -57.5  0.363     -15.431  0.134E-01   2.5  -0.134E+00  -0.179E-02
 31/01/1980  31    -65.0  0.375      -8.023  0.181E-02   2.3  -0.981E-01  -0.178E-03
 31/01/1980  31    -75.0  0.380       1.918  0.103E-03   2.0  -0.772E-01  -0.798E-05
 31/01/1980  31    -85.0  0.380      11.870  0.000E+00   1.9  -0.719E-01   0.000E+00
 31/01/1980  31    -95.0  0.380      21.826  0.000E+00   1.8  -0.657E-01   0.000E+00
 31/01/1980  31   -105.0  0.380      31.785  0.000E+00   1.7  -0.594E-01   0.000E+00
 31/01/1980  31   -115.0  0.380      41.749  0.000E+00   1.7  -0.532E-01   0.000E+00
 31/01/1980  31   -125.0  0.380      51.717  0.000E+00   1.6  -0.469E-01   0.000E+00
 31/01/1980  31   -135.0  0.380      61.689  0.000E+00   1.6  -0.406E-01   0.000E+00
 31/01/1980  31   -145.0  0.380      71.665  0.000E+00   1.6  -0.344E-01   0.000E+00
 31/01/1980  31   -155.0  0.380      81.645  0.000E+00   1.6  -0.281E-01   0.000E+00
 31/01/1980  31   -165.0  0.380      91.629  0.000E+00   1.6  -0.219E-01   0.000E+00
 31/01/1980  31   -175.0  0.380     101.617  0.000E+00   1.6  -0.156E-01   0.000E+00
 31/01/1980  31   -185.0  0.380     111.608  0.000E+00   1.7  -0.938E-02   0.000E+00
 31/01/1980  31   -195.0  0.380     121.604  0.000E+00   1.7  -0.313E-02   0.000E+00
…
 31/07/1980 213     -0.5  0.273     -84.571  0.643E+00  18.2   0.429E-01   0.276E-01
 31/07/1980 213     -1.5  0.275     -83.318  0.629E+00  18.1   0.438E-01   0.276E-01
 31/07/1980 213     -2.5  0.276     -82.068  0.666E+00  18.1   0.446E-01   0.297E-01
 31/07/1980 213     -3.5  0.278     -80.822  0.718E+00  18.1   0.453E-01   0.325E-01
 31/07/1980 213     -4.5  0.280     -79.580  0.782E+00  18.0   0.459E-01   0.359E-01
 31/07/1980 213     -5.5  0.281     -78.343  0.866E+00  18.0   0.465E-01   0.403E-01
…
 31/12/1980 366     -0.5  0.293     -69.869  0.816E-01   7.1  -0.150E+00  -0.122E-01
 31/12/1980 366     -1.5  0.294     -69.465  0.974E-01   7.1  -0.145E+00  -0.141E-01
 31/12/1980 366     -2.5  0.295     -69.033  0.114E+00   7.0  -0.139E+00  -0.159E-01
 31/12/1980 366     -3.5  0.295     -68.573  0.133E+00   7.0  -0.134E+00  -0.178E-01
 31/12/1980 366     -4.5  0.296     -68.084  0.154E+00   6.9  -0.128E+00  -0.198E-01
 31/12/1980 366     -5.5  0.297     -67.567  0.178E+00   6.8  -0.123E+00  -0.219E-01
 31/12/1980 366     -6.5  0.298     -67.022  0.205E+00   6.8  -0.118E+00  -0.241E-01
 31/12/1980 366     -7.5  0.298     -66.449  0.236E+00   6.7  -0.112E+00  -0.265E-01
 31/12/1980 366     -8.5  0.299     -65.849  0.270E+00   6.7  -0.107E+00  -0.289E-01
 31/12/1980 366     -9.5  0.300     -65.223  0.309E+00   6.6  -0.102E+00  -0.314E-01
 31/12/1980 366    -12.5  0.304     -63.248  0.436E+00   6.4  -0.875E-01  -0.382E-01
 31/12/1980 366    -17.5  0.310     -59.438  0.793E+00   6.2  -0.667E-01  -0.529E-01
 31/12/1980 366    -22.5  0.317     -55.234  0.136E+01   5.9  -0.516E-01  -0.699E-01
 31/12/1980 366    -27.5  0.325     -50.774  0.218E+01   5.7  -0.421E-01  -0.916E-01
 31/12/1980 366    -32.5  0.274     -45.977  0.325E+01   5.5  -0.354E-01  -0.115E+00
 31/12/1980 366    -37.5  0.288     -41.073  0.484E+01   5.4  -0.298E-01  -0.144E+00
 31/12/1980 366    -42.5  0.303     -36.135  0.715E+01   5.2  -0.256E-01  -0.183E+00
 31/12/1980 366    -47.5  0.319     -31.176  0.104E+02   5.1  -0.224E-01  -0.232E+00
 31/12/1980 366    -52.5  0.334     -26.203  0.145E+02   5.0  -0.199E-01  -0.289E+00
 31/12/1980 366    -57.5  0.348     -21.222  0.195E+02   4.9  -0.178E-01  -0.348E+00
 31/12/1980 366    -65.0  0.366     -13.739  0.273E+02   4.8  -0.157E-01  -0.429E+00
 31/12/1980 366    -75.0  0.379      -3.752  0.291E+02   4.7  -0.141E-01  -0.412E+00
 31/12/1980 366    -85.0  0.380       6.239  0.208E+02   4.6  -0.132E-01  -0.274E+00
 31/12/1980 366    -95.0  0.380      16.231  0.108E+02   4.5  -0.120E-01  -0.130E+00
 31/12/1980 366   -105.0  0.380      26.224  0.453E+01   4.5  -0.109E-01  -0.494E-01
 31/12/1980 366   -115.0  0.380      36.217  0.152E+01   4.5  -0.974E-02  -0.148E-01
 31/12/1980 366   -125.0  0.380      46.211  0.411E+00   4.5  -0.860E-02  -0.353E-02
 31/12/1980 366   -135.0  0.380      56.206  0.943E-01   4.5  -0.745E-02  -0.703E-03
 31/12/1980 366   -145.0  0.380      66.201  0.179E-01   4.5  -0.630E-02  -0.113E-03
 31/12/1980 366   -155.0  0.380      76.198  0.251E-02   4.5  -0.516E-02  -0.129E-04
 31/12/1980 366   -165.0  0.380      86.195  0.192E-03   4.6  -0.401E-02  -0.772E-06
 31/12/1980 366   -175.0  0.380      96.193  0.000E+00   4.6  -0.287E-02   0.000E+00
 31/12/1980 366   -185.0  0.380     106.191  0.000E+00   4.6  -0.172E-02   0.000E+00
 31/12/1980 366   -195.0  0.380     116.190  0.000E+00   4.6  -0.573E-03   0.000E+00
```

Annex B. List of routines of Swap version 2.0

Routine	Purpose
AFGEN	interpolate linearly in table
ANALIN	check if line is blank or comment
ASSIM	gross CO2 assimilation rate of the crop
ASTRO	daylength (astronomical and photoperiod)
BOCOBOT	calculate lower boundary conditions
BOCODRB	calculate basic, lateral drainage
BOCODRE	calculate extended, lateral drainage
BOCOTOP	calculate top boundary conditions
CALCGWL	search for groundwater levels
CRACK	calculate crack shrinkage and swelling, including fluxes
CROPD	WOFOST crop growth routine for SWAP
CROPS	simple crop growth routine for SWAP
DATONR	convert date into daynumber
DEVRIES	calculate soil thermal properties
DIVDRA	divide drainage flux to compartments
DMCNODE	calculate moisture capacity from pressure head
ERRHANDL	handle errors
FINDUNIT	find first free even unit number
FLUXES	calculate bottom and compartment fluxes
FROMTO	number of days between two given dates
GRASS	grass growth routine for SWAP
HCONODE	calculate hydraulic conductivity from water content
HEADCALC	calculate pressure heads at next time
INITSOL	initialize soil profile data
INTEGRAL	integrate intermediate and cumulative water fluxes
IRRIG	initialize and calculate irrigation
JMPLBL	jump to label NAME
LIMIT	limit variable between given boundaries
METEO	return meteorological data of actual day
NOCROP	specify crop characteristics for bare soil
NRTODA	convert daynumber into date
OUTAFO	formatted hydrological output for ANIMO/PESTLA (*.AFO)
OUTAIR	write irrigations (*.AIR)
OUTATE	write soil temperatures (*.ATE)
OUTAUN	unformatted hydrological output for ANIMO/PESTLA (*.AUN)
OUTBAL	write cumulative overview water and solute balance (*.BAL)
OUTDRF	write drainage fluxes, runoff, etc. (*.DRF)
OUTINC	write water balance increments (*.INC)
OUTSBA	write solute balance (*.SBA)
OUTSWB	write surface water balance (*.SWB)
OUTTEP	write soil temperatures (*.TEP)
OUTVAP	write water and solute profile data (*.VAP)
OUTWBA	write water balance (*.WBA)

PENMON	calculate potential evaporation and transpiration rates
PRHNODE	calculate pressure head from water content
QHTAB	calculate discharge from water level with table
RACHAR	read character array format free
RADATA	read array format free
RADIAT	calculate fluxes of diffuse and PAR radiation
RADOUR	read double precision array format free
RAINTR	read integer array format free
RAREAR	read real array format free
RDBBC	read bottom boundary condition
RDCRPD	read crop data (detailed model)
RDCRPS	read crop data (simple model)
RDDRB	read basic drainage
RDDRE	read extended drainage and surface water
RDGRASS	read grass data (detailed model)
RDHEA	read soil heat transport data
RDKEY	read general input file SWAP
RDSLT	read solute transport data
RDSOL	read soil hydraulic functions
RDSWA	read soil water and profile data
REDUCEVA	calculate actual soil evaporation
RFCHAR	read fixed number character array
RFDOUR	read fixed number, double precision array
RFINTR	read fixed number integer array
RFREAR	read fixed number, real array
ROOTEX	calculate actual water extraction by roots
RSCHAR	read single character value
RSDATA	read single data
RSDOUR	read single, double precision value
RSINTR	read singel integer value
RSREAR	read single real value
SHIFTL	shift character string to the left
SHIFTR	shift character string to the right
SKPLBL	verify label and return position of '='
SOIL	general soil routine
SLTBAL	calculate of solute balance
SOILTMP	calculate of soil temperatures
SOLUTE	calculate solute concentrations
STEPNR	find step number
THENODE	calculate water content from pressure head
TIMER	SWAP time keeper
TOTASS	calculate daily total gross assimilation
TRIDAG	solve a tridiagonal matrix
UPDATE	check hysteretic reversal and update scanning curve
WATCON	calculate water storage in soil profile and cracks
WBALLEV	surface water balance
WLEVBAL	surface water balance

WLEVST	surface water level from surface water storage
WSTLEV	surface water storage from surface water level
ZEROCUMU	reset cumulative water fluxes
ZEROINTR	reset intermediate water fluxes

Annex C. SWAP list with main variables

A

A := first Angstrom coefficient [-]
ACRACK := fraction of surface area occupied by cracks [-]
ADCRH := threshold level high atmospheric demand [cm]
ADCRL := threshold level low atmospheric demand [cm]
ADSFLU := array with adsorption flux crack ⇒ matrix [cm d^{-1}]
ALFAMG := array with alpha parameter in M-VG functions [$cm^{-1/2}$]
ALPHAW := array with alpha coefficient of weir discharge formula [$cm^{1-\beta}$ d^{-1}]
ALT := altitude above mean sea level [m]
AMAX := instantaneous gross assimilation rate at light saturation [kg ha^{-1} h^{-1}]
AMAXTB := AFGEN table: development stage [-] => max. CO_2 assimilation rate [kg ha^{-1} h^{-1}]
AQAMP := maximum deviation from AQAVE [cm]
AQAVE := average distance between water level in piezometer (located in deep aquifer) and ground surface [cm, negative when water level is below surface level]
AQOMEG := angular speed water level fluctuations [radians d^{-1}]
AQTAMX := first time the water level reaches its highest position [daynumber]
ARFLUX := nett rain flux at short time interval [cm d^{-1}]
ATMDEM := atmospheric evaporative demand [cm d^{-1}]
AVRAD := total daily shortwave radiation [J m^{-2} d^{-1}]

B

B := second Angstrom coefficient [-]
BASEGW := base of phreatic aquifer [cm]
BAYRD := beginning of agricultural year, daynumber since January 1st
BAYRY := beginning of agricultural year, yearnumber
BDENS := dry soil bulk density [g cm^{-3}]
BETAW := array with beta coefficient of weir discharge formula [-]
BEXP := exponent in reduction transformation due to dryness [-]
BOTCOM := array with compartment # at the bottom of each soil layer
BRUND := begin of simulation - daynumber (calendar year)
BRUNY := begin of simulation – year number

C

CDRAIN := initial solute concentration in aquifer [mg cm^{-3}]
CEVAP := cumulative actual soil evaporation [cm]
CGIRD := cumulative gross irrigation depth [cm]
CGRAI := cumulative gross rainfall [cm]
CH := crop height [m]
CHTAB := AFGEN table: development stage [-] => crop height [cm]
CIL := array with solute concentration in immobile soil water [mg cm^{-3}]
CIRR := solute concentration of irrigation water [mg cm^{-3}]
CISY := array with total concentration (solved+absorbed) in mobile volume [mg cm^{-3}]
CKWM1 := water storage in cracks during previous time step [cm]
CL := array with average solute concentration in soil water [mg cm^{-3}]
CML := array with solute concentration in mobile soil water [mg cm^{-3}]
CMLI := array with initial solute concentration per compartment [mg cm^{3}]
CMSY := array with total concentration (solved+absorbed) in mobile volume [mg cm^{-3}]
CNIRD := cumulative net irrigation depth [cm]
CNRAI := cumulative net rainfall [cm]

COFAB := precipitation interception coefficient [-]
COFANI := array with anisotropy factor of each layer [-]
COFGEN := array with Van Genuchten parameters
COFQHA := coefficient A in flux-groundwater level relationship [cm d^{-1}]
COFQHB := coefficient B in flux-groundwater level relationship [cm d^{-1}]
COFRED := soil evaporation coefficient [cm $d^{-0.5}$] or [$cm^{-0.5}$]
COSLD := amplitude of sine of solar height [-]
CPEVA := cumulative potential soil evaporation [cm]
CPOND := solute concentration in ponding water [mg cm^{-3}]
CPRE := solute concentration in rain water [mg cm^{-3}]
CPTRA := cumulative potential transpiration [cm]
CQBOT := cumulative flow depth through bottom of profile [cm]
CQCRACK := cumulative flow from cracks into matrix [cm]
CQDRA := cumulative total drainage flow depth [cm]
CQDRAIN := array with cumulative drainage flow depth per drainage level [cm]
CQDRAR := cumulative rapid drainage flow depth [cm]
CQDRD := cumulative total drainage flow into surface water reservoir [cm]
CQROT := cumulative root water uptake [cm]
CQTOP := cumulative flow depth through top of profile [cm]
CRACKC := solute concentration in cracks [mg cm^{-3}]
CRACKW := water storage in cracks [cm]
CRALEV := level of the crack bottom [cm]
CREF := reference solute concentration for adsorption [mg cm^{-3}]
CREF := reference solute concentration for adsorption [mg cm^{-3}]
CRUNO := cumulative surface runoff [cm]
CVL := efficiency of conversion into leaves [kg kg^{-1}]
CVO := efficiency of conversion into storage organs [kg kg^{-1}]
CVR := efficiency of conversion into roots [kg kg^{-1}]
CVS := efficiency of conversion into stems [kg kg^{-1}]
CWOUT := cumulative surface water discharge [cm]
CWSUPP := cumulative surface water supply [cm]

D

DAY := day number since beginning of the month
DAY1 := daynumber since start of calendar year of first date
DAY2 := daynumber since start of calendar year of second date
DAYL := astronomical daylength [h]
DAYLP := photoperiodic daylength [h]
DAYNR := day number since beginning of the calendar year
DAYSTA := daynumber (calendar year) at start of simulation run
DDAMP := damping depth [cm]
DDIF := molecular diffusion coefficient [cm^2 day^{-1}]
DECPOT := potential transformation rate [d^{-1}]
DECSAT := transformation rate in aquifer [d^{-1}]
DECTOT := cumulative solute amount transformed [mg cm^{-2}]
DIAMPOL := diameter soil matrix polygon [cm]
DIFDES := effective lateral diffusion coefficient [d^{-1}]
DIMOCA := array with differential moisture capacity at each node [cm^{-1}]
DISNOD := array with distance between a node and the one above [cm]
DistDrain := array with spacing between channels/drains [m]
DLC := lower threshold daylength pre-anthesis development [h]
DLO := optimum daylength pre-anthesis development [h]

DMCH := array with H-values of C(h) table [cm]
DNOCON := daynumber of day with no conversion
DPTRA := potential transpiration [cm]
DQROT := actual transpiration [cm]
DRAINL := array with depth of drainage base per level [cm]
DRAMET := method to calculate drainage flux
DRARES := array with drainage resistances [d]
DROPR := array with maximum drop rate of surface water level [cm d^{-1}]
DRZ := depth of the root zone [cm, negative]
DT := current timestep [d]
DTGA := daily total gross assimilation [kg ha^{-1} d^{-1}]
DTM1 := previous time step [d]
DTMAX := maximum value of timestep allowed [d]
DTMIN := minimum value of timestep allowed [d]
DTSMTB := AFGEN table: average temp. [C]=> daily increase temperature sum [C]
DTSOLU := time step modification due to solute transport [d]
DVSEND := development stage at harvest [-]
DZ := array with thickness of compartments [cm]

E

ECMAX := Ecsat level below which no salt stress occurs [dS m^{-1}]
ECSLOP := decline root water uptake above ECMAX [% dS^{-1} m^{-1}]
EFF := light use efficiency single leaf [(kg ha^{-1} h^{-1})/(J m^{-2} s^{-1})]
ENTRES := entrance resistance of the drain tube [d]
ENVSTR := path to project data directory
ERUND := end of simulation run – daynumber (calendar year)
ERUNY := end of simulation run – yearnumber
ES0 := potential evaporation rate from a bare soil [mm/d]
ET0 := potential transpiration rate from a dry crop [mm/d]
EW0 := potential transpiration rate from a wet crop [mm/d]

F

FCRACK := switch indicating if flow through cracks has to be considered
FDEPTH := array with reduction factor of potential transformation rate for each layer
FGROS := total instantaneous gross assimilation rate [kg ha^{-1} h^{-1}]
FLCROP := switch indicating presence of a crop
FLGENU := array describing how hydraulic properties of each soil layer are specified (VanGenuchten parameters or with a table)
FLLAST := flag indicating last timestep of a day
FLRAIC := flag indicating timestep correction due to detailed rainfall data
FLREVA := flag indicating how actual soil evaporation is obtained
FLTB := AFGEN table: development stage [-] => fraction of total above ground dry matter increase partitioned to the leaves [-]
FLTSAT := flag indicating profile is totally saturated
FluxDr := array with drainage/infiltration flux per drainage level [cm d^{-1}]
FluxDrComp := array with flux per node to/from each drainage level [cm d^{1}]
FM1 := array with corresponding mobile fractions [-]
FM2 := array with corresponding mobile fractions [-]
FMOBIL := array with volume fraction of mobile region in a compartment [-]
FOTB := AFGEN table: development stage [-] => fraction of total above ground dry matter increase partitioned to the storage organs [-]

FREXP := Freundlich (adsorption) exponent [-]
FRTB := AFGEN table: development stage [-] => fraction of total dry matter increase partitioned to the roots [-]
FSTB := AFGEN table: development stage [-] => fraction of total above ground dry matter increase partitioned to the stems [-]
FTOPH := flag indicating head- (T) or flux (F) controlled top boundary condition

G
GAMPAR := transformation reduction factor due to temperature [$°C^{-1}$]
GEOFAC := geometry factor Ernst [-]
GEOMF := geometry factor [-], (3 = isotropic shrink)
GIRD := gross irrigation rate [$cm\ d^{-1}$]
GRAI := gross daily rainfall rate [$cm\ d^{-1}$]
GWL := groundwater level [cm, negative = below surface level]
GWLBAK := array with last four groundwater levels [cm]
GWLCRIT := array with maximum value for GWL of phase IPHASE [cm]
GWLEV := groundwater level [cm, below surface is negative]
GWLI := initial groundwater level [cm, - = below surface level]
GWLINF := array with groundwater level for maximum infiltration [cm, neg.]
GWLTAB := AFGEN table with combinations of daynumber (T) and groundwater level [cm]

H
H := array with pressure head at each node [cm]
HAQUIF := thickness aquifer for solute breakthrough [cm]
HBWEIR := array with height of weir crest [cm]
HCRIT := array with critical pressure head at HDEPTH [cm]
HDEPTH := array depth in soil profile for comparing with HCRIT [cm, neg.]
HeaCap := array with heat capacity of each compartment [$J\ cm^{-3}\ K^{-1}$]
HeaCon := array with thermal conductivity at each node [$J\ cm^{-1}\ K^{-1}\ d^{-1}$]
HEAD := pressure head at current node [cm]
HGITAB := AFGEN table with combinations of daynumber and pressure head of lowest compartment [cm, negative= unsaturated]
HI := array with initial pressure head of each node [cm]
HLIM1 := start of root water extraction
HLIM2L := start of optimal extraction for all lower layers
HLIM2U := start of optimal extraction from upper soil layer
HLIM3H := end of optimal water uptake – high atmospheric demand
HLIM3L := end of optimal water uptake – low atmospheric demand
HLIM4 := end of water uptake (wilting point)
HM1 := H during previous timestep
HOUR := hour of the day (solar time) [h]
HQHTAB := array with hydraulic head above weir crest [cm]
HSURF := head top boundary condition [cm]
HTABLE := array with pressure head [cm] as a function of moist. content
HUM := vapour pressure [kPa]
HWLMAN := pressure head used for target level [cm]

I
IDAY := daynumber since January 1st [-]
IDSL := switch for pre-anthesis development
IEVAP := cumulative actual soil evaporation [cm]
IINTC := cumulative interception [cm]

ILTAB := length of the table;
IMPEND := array with time (T) that management period ends [d]
IMPER := index for current management period
INDEX := array with wetting curve [=1] or drying curve [=-1] indicators
INFRES := array with infiltration resistance per level [d]
INPOLA := array with relative location of upper boundary of compartment
INPOLB := array with relative location of lower boundary of compartment
INQ := array with cumulative flow depth through top of compartment [cm]
INQDRA := array with cumulative drainage flow depth per level per node [cm]
INQROT := array with cumulative root extraction volume per node [cm]
INTWL := length of water level adjustment period [d]
IPEVA := cumulative intermediate potential soil evaporation [cm]
IPOS := position of the drain tubes [-]
IPREC := cumulative intermediate precipitation [cm]
IPTRA := cumulative intermediate potential transpiration [cm]
IQBOT := cumulative intermediate flow depth through bottom of profile [cm]
IQCRACK := cumulative intermediate flow from cracks into matrix [cm]
IQDRA := cumulative intermediate total drainage flux [cm]
IQDRAR := cumulative intermediate rapid drainage flow depth [cm]
IQROT := cumulative intermediate whole root zone root water extraction [cm]
IRUNNR := number of the current single simulation run
IRUNO := cumulative surface runoff [cm]
ISCLAY := number of the soil layer involved in scaling
ISEQ := sequential [=1] or parallel run [=0]

J

K

K := array with hydraulic conductivity at each node + lower boundary [cm d^{-1}]
KCTAB := AFGEN table: development stage [-] => crop factor [-]
KDIF := extinction coefficient for diffuse light [-]
KDIR := extinction coefficient direct light [-]
KF := Freundlich (adsorption) coefficient [cm^3 mg^{-1}]
KFSAT := linear adsorption coefficient aquifer [cm^3 mg^{-1}]
KHBOT := horizontal hydraulic conductivity bottom layer [cm d^{-1}]
KHTOP := horizontal hydraulic conductivity top layer [cm d^{-1}]
KMEAN := array with arithmetic mean hydraulic conductivity between a node and the one above [cm d^{-1}]
KMOBIL := exchange rate between mobile-immobile parts [d^{-1}]
KSAT := array with saturated hydraulic conductivity of each layer [cm d^{-1}]
KSE99 := array with hydraulic conductivity at relative saturation of 0.99 [cm d^{-1}]
KTABLE := array with hydraulic conductivity [cm d^{-1}] as a function of moisture content
KVBOT := vertical hydraulic conductivity bottom layer [cm d^{-1}]
KVTOP := vertical hydraulic conductivity top layer [cm d^{-1}]
KYTAB := table: development stage[-] => yield response factor [-]

L

L := array with spacing between channels/drains [cm]
LAI := leaf area index [ha/ha]
LAIEM = leaf area index at emergence [ha ha^{-1}]
LAITB := AFGEN table: development stage [-] => leaf area index [ha ha^{-1}]
LAT := geographical latitude [degrees]

LAY := number of the soil layer involved
LAYER := array describing in which soil layer a node is situated
LCC := length of the crop cycle [d]
LDIS := dispersion length [cm]
LENGTH := length of the table

M
METFIL := name of the meteo station [-]
MOISR1 := moisture ratio at residual ⇒ normal shrink [-]
MOISRD := structural shrinkage [-]
MONTH := month number

N
NIRD := net irrigation flux [cm d^{-1}]
NMPER := number of management periods
NNCRACK := node number for evaluating shrinkage characteristic
NODE := number of the current node [-]
NODGWL := first unsaturated node (counted from below)
NODHD := array with compartment number related to HDEPTH
NOFRNS := number of runs
NPHASE := array with number of phases per management period
NQH := array with number of data pairs in QHTAB
NRAI := nett daily rainfall rate [cm d^{-1}]
NRLEVS := number of drainage levels
NRPRI := number of drainage levels in primary system
NRSEC` := number of drainage levels in secondary system
NRSRF := number of drainage levels
NUMADJ := counter for number of target level adjustments
NUMBIT := number of iterations
NUMCOMP := number of soil compartments
NUMDRAIN := number of drainage levels
NUMLAY := number of soil layers
NUMNOD := number of soil compartments

O
OSGWLM := criterium for warning about groundwater oscillation [cm]
OUTPER := counter
OVERFL := flag for overflow of automatic weir
OWLTAB := array with time ⇔water level in ditch [cm] relation

P
P1 := lower limit of the range
P2 := upper limit of the range
PARDIF := diffuse irradiance on a horizontal plane [J m^{-2} s^{-1}]
PARDIR := direct irradiance on a horizontal plane [J m^{-2} s^{-1}]
PercentClay := percentage of clay in dry soil
PercentSand := percentage of sand in dry soil
PERDL := maximum relative death rate of leaves due to water stress [d^{-1}]
PERIOD := output interval (days)
PEVA := potential soil evaporation rate [cm d^{-1}]
PF1 := array with pF values first data point (one for each layer) [-]
PF2 := array with pF values second data point (one for each layer) [-]

POND := thickness of ponding water layer [cm]
PONDM1 := ponding layer during previous timestep [cm]
PONDMX := maximum thickness of ponding layer [cm]
POROS := porosity of aquifer [-]
PTRA := potential transpiration rate [cm d^{-1}]

Q

Q := array with flow depth through top of compartment [cm]
Q10 := relative increase in respiration rate per 10 °C temperature increase [-]
QBOT := flux through bottom boundary of the profile [cm d^{-1},+=upward]
QBOTAB := AFGEN table with combinations of daynumber (T) and lower boundary flux [cm d^{-1}]
QCRACK := infiltration rate from cracks into soil matrix [cm d^{-1}]
QDRA := array with flux per node to/from each drainage level [cm d^{-1}]
QDRAIN := array with drainage/infiltration flux per dr. level [cm d^{-1}]
QDRD := drainage flux into surface reservoir [cm d^{-1}]
QDRTAB := array with drainage flux ⇔ groundwater level relationship
QDRTOT := total drainage flux [cm d^{-1}]
QIMMOB := array with flow depth per node to/from immobile phase [cm]
QQHTAB := array with related (see HQHTAB) discharge [cm d^{-1}]
QROSUM := total rootwater extraction flux [cm d^{-1}]
QROT := array with root extraction flux per node [cm d^{-1}]
QTOP := top boundary flux [cm d^{-1}]

R

RAD := incoming short wave radiation [J/m^2/d]
RAPCOEFF := rate coefficient bypass flow from cracks to drains [d^{-1}]
RAPDRA := bypass flow rate to drains/ditches [cm d^{-1}]
RCC := reflection coefficient crop [-]
RCS := reflection coefficient soil [-]
RDC := maximum rooting depth crop [cm]
RDCTAB := table: datapairs of root distribution coefficient [-] as a function of fraction of maximum rooting depth [-]
RDI := initial rooting depth [cm]
RDM := maximum rooting depth [cm,+]
RDRAIN := array with drainage resistance [d]
RDRRTB := AFGEN table: development stage [-] => rel. death rates of roots [kg kg^{-1} d^{-1}]
RDS := maximum rooting depth allowed by the soil [cm]
RDTAB := AFGEN table: development stage [-] => rooting depth [cm]
RENTRY := array with entry resistance [d]
RER := relative error in stop criterium for calculation of non-linear ads [-]
REVA := actual soil evaporation rate [cm d^{-1}]
REXIT := array with exit resistance [d]
RFSETB := AFGEN table: development stage [-] => reduction factor for senescence [-]
RGRLAI := maximum relative increase in leaf area index [ha ha^{-1} d^{-1}]
RIMLAY := vertical resistance of semi-permeable layer [d]
RINFI := array with infiltration resistance [d]
RML := relative maintenance respiration rate leaves [kg CH_2O kg^{-1} d^{-1}]
RMO := relative maintenance resp. rate storage organs [kg CH_2O kg^{-1} d^{-1}]
RMR := relative maintenance resp. rate roots [kg CH_2O kg^{-1} d^{-1}]
RMS := relative maintenance resp. rate stems [kg CH_2O kg^{-1} d^{-1}]
ROTTOT := cumulative solute amount taken up by the crop [mg cm^{-2}]
RRI := maximum daily increase in rooting depth [cm d^{-1}]

RSIGNI := sgnificance threshold daily rainfall [cm]
RSRO := drainage resistance of surface runoff [d]
RTHETA := minimum water content for potential transformation rate [-]
RUNNR := number of current single run
RUNOTS := runoff flux during current timestep [cm d^{-1}]

S

SAMAQ := solute storage in saturated groundwater [mg cm^{-2}]
SAMCRA := solute storage in partly filled cracks [mg cm^{-2}]
SAMINI := initial solute storage in soil profile [mg cm^{-2}]
SAMPRO := solute storage in soil profile [mg cm^{-2}]
SHAPE := shape factor of groundwater [-]
SHRINA := limit of void ratio at zero water content [-]
SHRINB := fitting parameter shrinkage characteristic [-]
SHRINC := fitting parameter shrinkage characteristic [-]
SINB := sine of solar elevation [degrees]
SINLD := seasonal offset of sine of solar height [-]
SLATB := AFGEN table: development stage [-] => specific leaf area [ha kg^{-1}]
SLOPFM := array with slope of the pF-FM relation
SLOPFM := slope of the pF-FM relation
SPA := specific pod area [ha kg^{-1}]
SPAN := life span of leaves [d] under optimum temp. & light conditions
SQBOT := cumulative solute amount through bottom soil profile [mg cm^{-2}]
SQDRA := cumulative solute amount profile => drain/ditch [mg cm^{-2}]
SQRAP := cumulative solute amount crack => drain/ditch [mg cm^{-2}]
SQSUR := cumulative solute amount saturated zone => drain/ditch [mg cm^{-2}]
SQTOP := cumulative solute amount through top soil profile [mg cm^{-2}]
SSA := specific stem area [ha kg^{-1}]
STRING := character string to be left or right aligned;
STTAB := array with surface water storage as a function of surface water level [cm]
SWAFO := switch for output of formatted hydrological data
SWAIR := switch for output of irrigation data
SWALLO := array with switches for allowance drainage/infiltration [-]
SWANAF := switch for output of soil profile data
SWATE := switch for output of soil temperature profiles
SWAUN := switch for output of unformatted hydrological data
SWBOTB := active option for bottom boundary condition [-]
SWDRA := switch for simulation of drainage
SWDRF := switch for output of drainage fluxes (extended drainage option)
SWDTYP := array with type of drainage media [-]
SWETR := switch for use of ETref column in meteo files
SWHYST := switch for hysteresis options
SWINCO := switch for initial moisture condition options
SWMAN := array with type of water management [1=fixed weir, 2=automatic weir]
SWMOBI := switch indicating if soil contains immobile water
SWNUMS := type of implicit scheme used [-]
SWQHR := switch indicating type of weir discharge relationship [-]
SWREDU := options for reduction of soil evaporation
SWSCAL := switch for similar media scaling
SWSEC := switch indicating surface water is simulated or input
SWSOLU := switch for simulation of solute transport
SWSRF := switch for specification of the surface water system

SWSRFO := switch for output of water balance surface water reservoir
SWTEMP := switch indicating presence of temperature data

T

T := time since start of the agricultural year [d]
TABLE := name of the table
TALUDR := array with side slope of channel [dh/dw]
TAMPLI := amplitude of annual temperature wave at soil surface [°C]
TAU := minimum head difference for change scanning curve [cm]
TAV := average day temperature [°C]
TBASE := lower threshold temperature for ageing of leaves [°C]
TCUM := time since begin of simulation run [d]
TDWI := initial total crop dry weight [kg ha^{-1}]
TEMP := array with temperature at surface and nodal points [°C]
TEMPI := array with initial values for TEMP [°C]
THETA := array with volumetric moisture content of a node [cm^3 cm^{-3}]
THETAI := array with initial moist. content of each compartment [cm^3 cm^{-3}]
THETAR := array with nodal residual water content [cm^3 cm^{-3}]
THETAS := array with nodal saturated water content [cm^3 cm^{-3}]
THETCR := critical theta for depth of cracks [-]
THETHI := array with pointer to highest theta values in HTABLE
THETIM := array with volumetric water content in immobile soil parts [cm^3 cm^{-3}]
THETLO := array with pointer to lowest theta values in HTABLE
THETM1 := array with nodal moisture content at previous time step [cm^3 cm^{-3}]
THETOL := stop criterium iteration procedure
THETSL := array with saturated volumetric water content of each layer [cm^3 cm^{-3}]
ThickComp := array with thickness of the compartments [cm]
TIMREF := time at start of sine temperature wave [day#]
TMEAN := mean annual temperature at soil surface [°C]
TMNFTB := AFGEN table: low minimum temperature [C] => reduction factor of AMAX [-]
TMPFTB := AFGEN table: average temperature[C] => reduction factor of AMAX [-]
TSCF := solute (root)uptake factor [-]
TSUMAM := temperature sum from anthesis to maturity [°C]
TSUMEA := temperature sum from emergence to anthesis [°C]

U

V

VCRIT := array with critical unsaturated volume [cm]
VOLACT := water storage in the soil profile [cm]
VOLINI := initial total volume of water in the soil profile [cm]
VOLM1 := VOLACT during previous time step [cm]
VOLSAT := volume of water in the saturated soil profile [cm]
VTAIR := total air volume in soil profile [cm]

W

WCON := moisture content at current node [-]
WETPER := array with wet perimeter of the drains [cm]
WIDTHR := array with bottom width of channel [cm]
WIN := windspeed at 2 meter height [m/s]
WLDIP := array with allowed dip of surface water level, before starting supply [cm]

WLEV	:= surface water level [cm]
WLP	:= surface water level primary system [cm]
WLPTAB	:= AFGEN table with combinations specifying water level in the primary system [cm, neg.] as a function of time
WLS	:= surface water level secondary system [cm]
WLSBAK	:= arraywith water levels secondary system at past four timesteps [cm]
WLSMAN	:= array with surface water level of phase IPHASE [cm]
WLSTAB	:= AFGEN table with combinations specifying water level in the secondary system [cm, neg.] as a function of time
WLSTAR	:= target level of surface water [cm]
WSCAP	:= array with surface water supply capacity [cm d^{-1}]
WST	:= current surface water storage [cm]
WSTINI	:= initial surface water storage [cm]
WSTOR	:= surface water storage [cm]
WTOPLAT	:= lateral surface flow into cracks [cm]

X

X	:= value of the independent variable (AFGEN, STEPNR)
X	:= parameter to restrict (LIMIT)

Y

YEAR	:= year number
YEAR1	:= year number of first date
YEAR2	:= year number of second date

Z

Z	:= array with position of nodal points [cm, negative]
ZBOTDR	:= array with bottom of drainage medium [cm, neg.]
ZINTF	:= depth of the interface between the two layers [cm]
ZNCRACK	:= depth where crack area soil surface is calculated [cm]

Annex D. Description of the output files *.afo and *.aun

This annex describes the content of the output files with extension *.afo and *.aun. The content of both files is identic; they only differ in format: one file is binary and unformatted (*.aun) and the other file is formatted (*.afo). The description given in this annex uses the following symbols:

– Unit = units as theyu are applied in these files; units may differ from those applied in Swap !
– R = data are written to a new record;
– DT = data type; R means Real*4, I means Integer*2;
– Mnemonic = the name of the variable as applied in the source code of Swap

Description of variable	Unit	Range	R	DT	Mnemonic
Time domain					
Year when hydrological simulation started	-	[1. .4>	*	I	bruny
Year when hydrological simulation ended	-	[bruny..4>	-	I	eruny
Time (Julian daynumber) when hydrological simulation started (Minimum); will be 0.0 when simulation started at 1st of January, 00.00 hour.	-	[0.0..4>	-	R	brund-1
Time (Julian daynumber) when hydrological simulation ended (Maximum)	-	[0.0..4>	-	R	erund
Stepsize of time-interval for dynamic hydrological data	d	[1.0..30.0]	-	R	period
Geometry of model system					
Number of model compartments	-	[1 ..numnod]	*	I	numnod
Number of horizons	-	[1 ..numlay	-	I	numlay
Number of drainage systems (value must be 0, 1, 2, 3 or 4)	-	[0,1,2,3,4]	-	I	nrlevs
The following 4 variables (botcom – thetawp) are given for the horizons 1 – numlay:					
Compartment number of the deepest compartment (bottom) of each horizon/layer	-	[1 ..numnod]	*	I	botcom(numlay)
Volume fraction moisture at Saturation	$m^3\ m^{-3}$	[0.0 .. 1.0]	*	R	thetas (numlay)
Volume fraction moisture at Field Capacity	$m^3\ m^{-3}$	[0.0 .. 1.0]	*	R	thetafc(numlay)
Volume fraction moisture at Wilting point	$m^3\ m^{-3}$	[0.0 .. 1.0]	*	R	thetawp(numlay)
The following variable dz is given for the compartments 1 – numnod					
Thickness of compartments	m	[0.001..100]	*	R	dz(numnod)

Description of variable	Unit	Range	R	DT	Mnemonic
Initial conditions					
The following variable theta is given for the compartments 1 – numnod					
Volume fraction moisture inItially present in compartments 1 – NUMNOD	$m^3\ m^{-3}$	[0.0 .. 1.0]	*	R	theta(numnod)
InItial groundWAterlevel	m-surface	[0.0..4>	*	R	gwl
Storage by inItial ponding (m+surface)	m+ surface	[0.0..4>	-	R	pond
Dynamic part					
Time (Julian daynumber) in hydrological model	-	[0.0..4>	*	R	tcum
Precipitation (***incl. irrigation***) water flux	$m\ d^{-1}$	[0.0..4>	-	R	iprec
Evaporation flux by interception	$m\ d^{-1}$	[0.0..4>	-	R	iintc
Actual evaporation flux by bare soil	$m\ d^{-1}$	[0.0..4>	-	R	ievap
Evaporation flux by ponding	$m\ d^{-1}$	[0.0]	-	R	0.0
Potential evaporation flux by soil	$m\ d^{-1}$	[0.0..4>	-	R	ipeva
Potential transpiration flux	$m\ d^{-1}$	[0.0..4>	-	R	iptra
Flux of surface RUnoff	$m\ d^{-1}$	[0.0..4>	-	R	iruno
GroundwAter level at end of time-interval	m-surface	[0.0..4>	-	R	gwl
Storage by ponding at soil surface at end of time-interval	m+ surface	[0.0..4>	-	R	pond
The variables h - inqdra are given for the compartments 1 - numnod, with one exception for inq, which is given for the compartments 1 – numnod+1					
Suction (pressure head) of soil moisture (negative when unsaturated)	cm	<-4..+4>	*	R	h(numnod)
Volume fraction of moisture at end of time-interval	$m^3\ m^{-3}$	[0.0 .. 1.0]	*	R	theta(numnod)
Actual transpiration flux	$m\ d^{-1}$	[0.0..4>	*	R	inqrot(numnod)
Flux incoming from above (compartments 1 – numnod+1, downward=positive)	$m\ d^{-1}$	[0.0..4>	*	R	inq(numnod+1)
The presence of values for variables inqdra1-inqdra4 is determined by the variable nrlevs. The value of nrlevs determines the number of drainage systems for which flux densities must be given.					
Flux of drainage system of 1st order (canal)	$m\ d^{-1}$	[0.0..4>	*	R	inqdra(1,numnod)
Flux of drainage system of 2nd order (ditch)	$m\ d^{-1}$	[0.0..4>	*	R	inqdra(2,numnod)
Flux of drainage system of 3rd order (trench)	$m\ d^{-1}$	[0.0..4>	*	R	inqdra(3,numnod)
Flux of drainage system of 4th order (tube drain)	$m\ d^{-1}$	[0.0..4>	*	R	inqdra(4,numnod)

Annex E. Summary of input data

General information (Swap.key)
Environment
Time variables
Meteorological data
In- and output files for the sub-runs
Processes which should be simulated
Optional output files

Daily meteorological data (*.yyy)
Radiation, temperature, vapour pressure, wind speed, rainfall and/or reference evapotranspiration

Detailed rainfall (*r.yyy)
Actual rainfall intensities

Fixed irrigation (*.irg)
Amount and quality of prescribed irrigation applications

Calculated irrigation (*.cap)
Type of irrigation
Irrigation timing criteria
Irrigation depth criteria

Crop calendar (*.cal)
Crop data input file
Calculated irrigation input file
Crop emergence and harvest
Start irrigation scheduling

Detailed crop growth (*.crp)
Crop height
Crop development
Initial values
Green surface area
Assimilation
Assimilates conversion into biomass
Maintenance respiration
Dry matter partitioning
Death rates
Crop water use
Salt stress
Interception
Root growth and density distribution

Simple crop growth (*.crp)
Crop development
Light extinction
Leaf area index
Soil cover fraction
Crop height

Rooting depth
Yield response
Crop water use
Salt stress
Interception
Root density distribution

Water in soil profile (*.swa)
Ponding
Reduction soil evaporation
Time discretization flow equation
Spatial discretization
Files with soil hydraulic functions
Maximum rooting depth
Hysteresis of soil water retention function
Similar media scaling
Preferential flow due to soil volumes with immobile water
Preferential flow due to cracks
Vertical distribution drainage flux
Initial moisture condition

Soil hydraulic functions (*.sol)
Soil water retention function
Unsaturated hydraulic conductivity function

Basic drainage (*.drb)
Table of drainage flux - groundwater level
Drainage formula of Hooghoudt or Ernst
Drainage and infiltration resistances

Extended drainage (*.dre)
Drainage characteristics
Surface water level of primary and/or secondary system
Simulation of surface water level
Weir characteristics

Bottom boundary conditions (*.bbc)

Heat flow (*.hea)
Analytical or numerical method

Solute transport (*.slt)
Top boundary and initial condition
Diffusion and dispersion
Solute uptake by roots
Adsorption
Decomposition
Transfer between mobile and immobile water volumes
Residence in saturated zone

Annex F. Summary of output data

Total water and solute balance (*.bal)
Final and initial water and solute storage
Water balance components
Solute balance components

Incremental water balance components (*.inc)
Gross rainfall
Gross irrigation
Interception
Runoff
Potential and actual transpiration
Potential and actual evaporation
Net drainage
Net bottom flux

Cumulative water balance components (*.wba)
Gross and net rainfall
Gross and net irrigation
Runoff
Potential and actual transpiration
Potential and actual evaporation
Net lateral flux (drainage)
Net bottom flux
Change water storage in profile
Groundwater level
Water balance error

Cumulative solute balance components (*.sba)
Flux at soil surface
Amount decomposed
Amount taken up by plant roots
Amount in soil profile
Amount in cracks
Flux at soil profile bottom
Drainage flux
Bypass flux from cracks
Amount in defined saturated aquifer
Flux from defined saturated aquifer

Soil temperatures (*.tep)
Soil temperature of nodes 1,6,11, etc.

Soil profiles (*.vap)
Profiles of water content, pressure head, solute concentration, temperature, water flux and root water uptake

Irrigation (*.sc*)
Calculated irrigation applications

Detailed crop growth (*.cr*)
Development stage
Leaf area index
Crop height
Rooting depth
Cumulative relative transpiration during 0-2 DVS
Cumulative relative transpiration during 1-2 DVS
Cumulative potential and actual weight of dry matter
Cumulative potential and actual weight of storage organ

Simple crop growth (*.cr*)
Development stage
Leaf area index
Crop height
Rooting depth
Cumulative relative transpiration
Cumulative relative crop yield

Extended drainage components (*.drf)
Drainage fluxes of each level
Total drainage flux
Net runoff
Rapid drainage

Surface water management 1 (*.swb)
Groundwater level
Weir target level
Surface water level
Storage in surface water reservoir
Sum of drainage, runoff and rapid drainage
External supply to surface water reservoir
Outflow from surface water reservoir

Surface water management 2 (*.man)
Weir type
Groundwater level
Pressure head for target level
Total air volume in soil profile
Weir target level
Surface water level
Surface water outflow
Number of target level adjustments
Indicator weir overflow
Weir crest level

Final pressure heads (Hfinal.dat)
Final pressure heads

Log file (SWAP207.log)
Error mess